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WAR DEPARTMENT

Report 834

EFFICIENCY OF STANDARD ARMY WATER PURIFICATION EQUIPMENT AND OF DIATOMITE FILTERS IN REMOVING CYSTS OF ENDAMOEBA HISTOLYTICA FROM WATER

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EFFICIENCY OF STANDARD ARMY WATER PURIFICATION EQUIPMENT AND OF DIATOMITE FILTERS IN REMOVING CYSTS OF ENDAMOEBA HISTOLYTICA FROM WATER

Project WSS 346

3 July 1944

Submitted to

THE ENGINEER BOARD

Fort Belvoir, Virginia

and/or

The Chief of Engineers

U. S. Army Corps of Engineers

Washington, D. C.

FOR OFFICIAL ACTION

by

Water Supply Equipment Branch
Technical Division III
The Engineer Board
Fort Belvoir, Virginia

and

National Institute of Health
U. S. Public Health Service

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TABLE OF CONTENTS

SYLLABUS

1. Scope.

a. Introduction. This report covers a study of the removal of the cysts of Endamoeba histolytica from water by pressure type filtration. The work was conducted in cooperation with the National Institute of Health, United States Public Health Service.

b. Equipment. The study treated herein was divided into two major phases:

(1) Tests using the U. S. Army Portable Water Purification Unit, Model 1940, both with and without pretreatment of the raw water.

(2) Tests using several types of diatomaceous silica filters including the U, S. Army Portable Water Purification Unit converted for use with diatomaceous silica.

2. Results. The results of this study show that:

a. The complete removal of cysts of Endamoeba histolytica is not accomplished with the sand filter of the U. S. Army Portable Water Purification Unit when operated at flow rates practical for field use.

b. Sedimentation alone for short periods is not effective in removing cysts from water.

c. The total number of cysts in a quantity of water is reduced by good coagulation and sedimentation.

d. Pressure type filters using any of the diatomaceous silica filter aids considered in the study will remove cysts of Endamoeba histolytica.

e. The combination of pretreatment, sedimentation, and filtration gives results considerably better than filtration alone.

3. Recommendations. In view of the findings of this study of the removal of cysts of Endamoeba histolytica from water, it is recommended that:

a. The output of the U. S. Army Portable Water Purification Unit Model 1940 be reduced from 15 gallons per minute to

10 gallons per minute as a maximum, and that this output be further reduced to not greater than 7.5 gallons per minute whenever possible.

b. The output of the U. S. Army Mobile Water Purification Unit, Model 1940, be reduced from 75 gallons per minute to 60 gallons per minute as a maximum, and that this output be further reduced to not greater than 45 gallons per minute whenever possible.

(It must be understood that this reduction in output, while increasing the factor of safety, does not mean that complete removal of the cysts of *Endamoeba histolytica* is assured by adherence to the procedure recommended above.)

c. One hour of detention be provided for coagulating, settling and prechlorinating all raw water without exception prior to filtration through either of the sand units.

d. Field water quality control equipment be supplied to all units in the field, which shall, among other things, provide equipment for conducting jar tests and for the evaluation of the efficiency of filtration in terms of turbidity removal.

e. The study of diatomaceous silica now being conducted by the Engineer Board be continued to the end of determining the feasibility of the adoption of diatomaceous silica filtration equipment to replace the sand filters now in use.

f. Studies of the epidemiology of amoebic dysentery in the armed forces of the United Nations be encouraged, and the reports from the field be examined to determine the magnitude of the part that water may be playing in the dissemination of amoebic dysentery.

EFFICIENCY OF STANDARD ARMY WATER PURIFICATION EQUIPMENT AND OF DIATOMITE FILTERS IN REMOVING CYSTS OF ENDAMOEBA HISTOLYTICA FROM WATER

I. SUBJECT

1. Scope. This report covers a study of the efficiency of standard Army water purification equipment and of diatomite filters in removing cysts of *Endamoeba histolytica* from water. Included is a summary of the work completed to date, descriptions and photographs of the equipment used, and recommendations relative both to the development of new equipment and to changes in the techniques of operating existing equipment.

II. AUTHORITY

2. Authority. Authority for initiating a study of the efficiency of filtration in removing cysts of *Endamoeba histolytica* from water is contained in a letter from the Chief of Engineers to the Engineer Board dated 19 March 1943, file SPESD, subject: Study of Effectiveness of Army Purification Methods in Removing Cysts of *Endamoeba histolytica*. In this letter the Board was directed to cooperate with the Surgeon General's Office and the National Institute of Health in a program for the study of the removal of the cysts of *Endamoeba histolytica*. A copy of this letter is contained in Appendix A.

III. INVESTIGATION

3. Introduction. There is no record in the technical literature of a previous study of the removal of cysts of *Endamoeba histolytica* from water by pressure type filtration. Filtration studies of this general type have been conducted by Baylis, Gullans, and Spector[1], but their work was confined to gravity head filters and operation at lower filtration rates than those covered in this study. The work done in this study with diatomaceous silica has no precedent. This study was initiated after work by Brady, Jones, and Newton[2] as well as other

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1 J. R. Baylis, O. Gullans, and B. K. Spector, "The Efficiency of Rapid Sand Filters in Removing the Cysts of the Amoebic Dysentery Organisms from Water," *Public Health Report* 51 (Nov. 13, 1936), 1567-1575; B.K. Spector, J.R. Baylis, and O. Gullans, "Effectiveness of Filtration in Removing from Water, and of Chlorine in Killing, the Causative Organism of Amoebic Dysentery," *Public Health Report* 49 (July 6,1934),786-800.

2 F. J. Brady, Myrna F. Jones, and W. L. Newton, "Effect of Chlorination of Water on Viability of Cysts of Endamoeba Histolytica," *War Medicine*, III (April, 1943), 409-419.

investigators had indicated that normal dosages of chlorine cannot be depended upon to destroy amoebic cysts. It was desired to determine the efficiency of standard Army water purification processes and equipment in removing cysts of Endamoeba histolytica from water.

4. Equipment and Apparatus.

a. Sand Filter. The sand filter unit used in the tests hereinafter described is a U. S. Army Portable Water Purification Unit, Model 1940. Essentially, the unit consists of a gasoline engine-driven centrifugal pump, a pressure filter, a belt-driven hypochlorinator, an alum and soda ash feed assembly, and necessary hose with fittings (Figure 1). The filter consists of an inclosed monel metal tank (17-inch inside diameter), outlet piping, control valves, pressure gages, and an internal collecting and distributing system. The filter bed consists of 18 inches of graded sand, effective size of 0.36 mm, uniformity coefficient of 1.35, resting on four inches of fine gravel. An analysis of the sand used is shown in Figure 54, Appendix C, while the characteristics of the sand as specified are given in Figure 55, Appendix C. A perforated monel plate separates the sand and gravel. For these tests the filter bed of 1.57 square feet of surface was replaced for each test with new sand. The coagulants of ammonium alum and soda ash are fed into the raw water at the pump suction from two differential pressure pots operating across a venturi throat. The chlorinator was used during these tests as a constant feeding device for the feeding of cysts to the raw water. No chlorine was used in any of the tests. A 1/4-inch line was tapped into the pump suction and equipped with a quick-opening petcock for batch application of cysts.

b. Diatomaceous Silica Filters. The following diatomaceous silica filters were used in this study:

(1) Stoneheart Engineering Company, Model SF-1, 0.125 gpm. This unit consists of a reservoir and a pressure filter containing a Stoneheart porous filter element 0.125 square feet in area (Figure 2). The filter is suspended from the reservoir by 30 inches of 1/4-inch plastic-coated fabric hose equipped with a shut-off clamp. The unit utilizes the static head to force the water from the reservoir through the filter.

(2) Wallace and Tiernan Company, Incorporated, Model G2, 40 gph. This unit is likewise of the gravity type, being so constructed as to provide a maximum head of 5 feet (Figure 3). The filter element used in this unit is a monel metal screen.

(3) S. F. Bowser and Company, Incorporated, Model 2MS, 60-100 gph. This filter consists of a filter shell containing

a wire screen element 2 square feet in area, a hand-operated pump mounted on the filter head, and a body feed assembly (Figure 4). Provision is made for recirculating the water used to precoat the unit.

(4) S. F. Bowser and Company, Incorporated, Model 1.5C, 60-100 gph. This unit is identical with the earlier model 2MS with the exception of the element, which in this case is a porous carbon element 1.5 square feet in area.

(5) International Filter Company, Incorporated, Model SW 1/8, 0.375 gpm. The model SW 1/8 is a laboratory test assembly consisting of a glass filter shell containing a Stellar element 0.125 square feet in area and a small electric motor-driven pump (Figure 5). The Stellar element used is identical in design and construction with elements in diatomaceous silica filters used by the British Army.

(6) Naval Medical Research Institute Experimental Model. This gravity type unit consists of a vinylite bag in which is mounted a porous carbon disc of 8 square inches in area. The unit may be rolled up and carried in one's pocket.

(7) Stoneheart Engineering Company, Model SF-X1, 20 gpm. This unit consists of a filter shell and head assembly, four Stoneheart ceramic filter elements totaling 8.8 square feet in area, a gasoline-engine-driven centrifugal pump, a turbine pump connected to the same engine, an electrically-driven body feed pump, a precoat tank and a hypochlorinator (Figure 6). In this study, only the filter section and precoat tank were used. The treatment section of a U. S. Army Portable Water Purification Unit was used to pump the raw water.

(8) U. S. Army Portable Water Purification Unit, Model 1940, Converted for Use with Diatomaceous Silica. A filter of the same type as used in the tests with sand was converted for use with diatomaceous silica (Figure 7). This unit contained 6.6 square feet of filtering surface consisting of three aluminum oxide filter elements. The body treatment was added through the pump suction and was controlled by a simple valve and sight glass assembly.

c. Settling Tanks. Two sizes of sedimentation tanks were used in this study: first, a 2500-gallon steel tank measuring 8 feet in diameter; and, second, a U. S. Army 3000-gallon canvas tank measuring 11.25 feet in diameter. The latter tank is standard issue with all purification units in the field (Figure 8).

d. Metering and Sampling. A Pittsburgh water meter (No. 3399364) was used to determine all output rates above 5 gallons

per minute, and a system of outlet taps installed in the discharge line permitted the simultaneous collection of the several samples.

e. Chemical Analyses. The pH determinations at the filter were made with a standard comparator supplied with the U. S. Army Portable Water Purification Unit. The pH determinations in the laboratory were made with a Beckmann pH meter. All chemical analyses were conducted in accordance with standard methods.

f. Preparation of and Examination for the Organism. The NRS strain of *Endamoeba histolytica* was used throughout these tests because cysts could be prepared with relative ease and because its size, averaging 15.2 $\mu \pm 2\ \mu$, corresponds to the large, more pathogenic strain of *E. histolytica*. To procure the cysts, amoebae maintained on egg slant cultures with an overlay of Stone's modification of Locke's solution were transferred to tubes of a similar medium containing a small amount of rice starch. After 72 hours of incubation with this medium, the cysts were harvested, washed in distilled water, and stored in the refrigerator at least 24 hours before use. Estimates of the numbers of cysts were made with the use of the Fuchs-Rosenthal counting chamber, while the identification and counting of the cysts present in the effluent samples were made in a Sedgwick-Rafter counting cell.

5. Tests. The tests covered by this report consisted essentially of introducing a predetermined number of cysts of the NRS strain into the raw water, passing this water through filters, and collecting samples of the effluent at regular intervals for microscopic examination. When preliminary treatment consisting of coagulation and sedimentation was employed, a uniform suspension of cysts in the water to be treated was obtained by introducing the organism into the water at a constant rate during the period that the settling tank was being filled. Chemical and bacterial analyses of the influent and effluent of a number of tests were made as an additional control. Operation of equipment and chemical analyses were performed by the Technical Staff of the Engineer Board Water Supply Equipment Branch; the incubation and harvesting of the cysts and the microscopic examination were performed at the National Institute of Health.

In general, the method used for the examinations of water samples for cysts was as follows: Samples of effluent waters were allowed to settle in a cool place for 18 to 24 hours. The supernatant was then gently siphoned off and the remainder placed in smaller bottles. To these containers, ammonium alum and soda ash were added, and the containers were left in the cold room over night. The supernatant was again siphoned off and the remainder placed in 50-cc centrifuge tubes. By centrifugation, the sediment from each tube was again concentrated. One or two cubic centimeters of M/10 oxalic acid were added to redissolve the coagulum and the volume

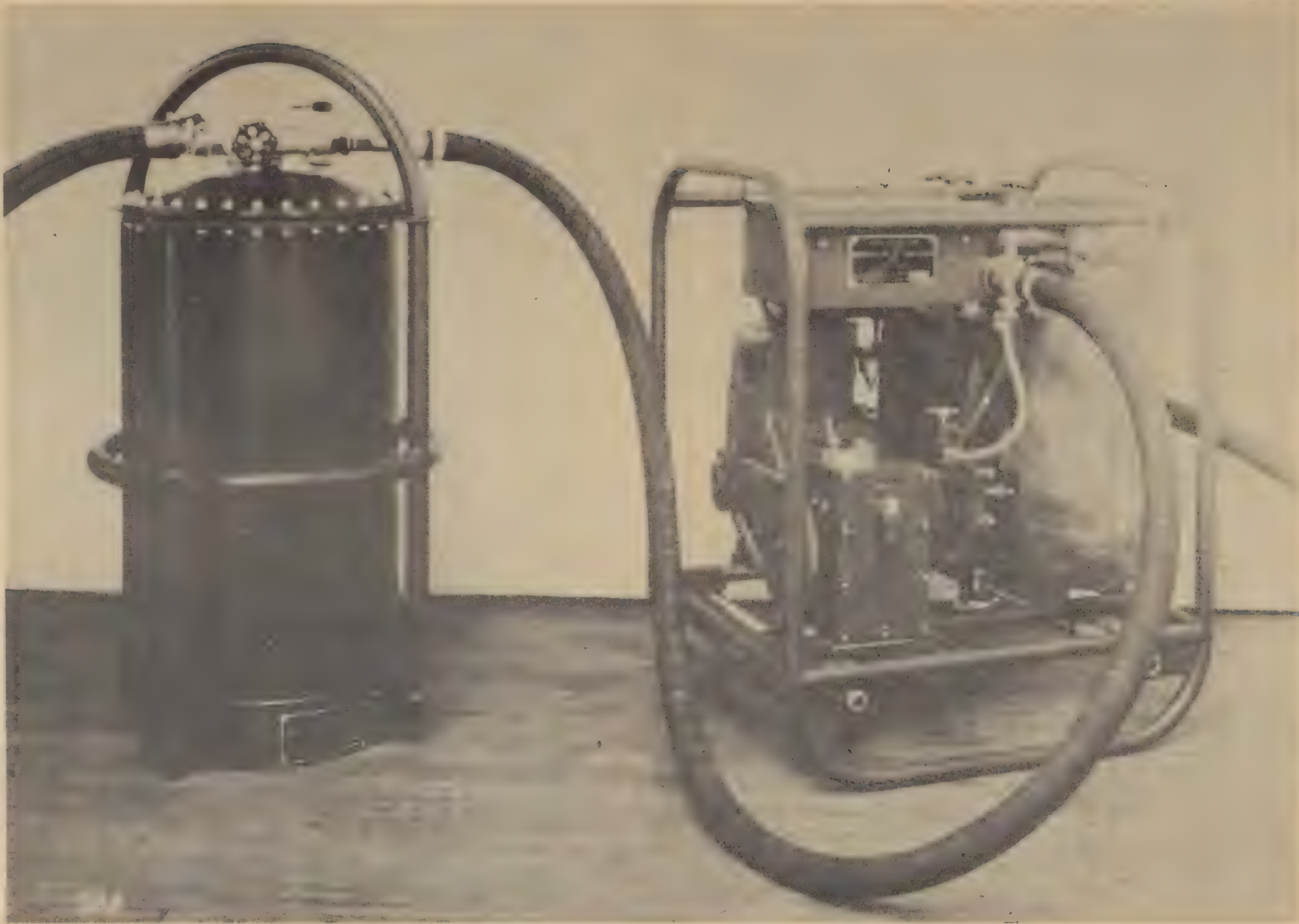

FIG. 1. U. S. ARMY PORTABLE WATER PURIFICATION UNIT, MODEL 1940. Assembled for operation.

FIG. 2. GRAVITY TYPE DIATOMITE FILTER. Stoneheart Engineering Company, Model SF-1.

FIG. 3. GRAVITY TYPE DIATOMITE FILTER. Wallace and Tiernan Company, Model G-2.

FIG. 4. HAND-OPERATED DIATOMITE FILTER. S. F. Bowser and Company, Inc., Model 2MS.

FIG. 5. STELLAR DIATOMITE FILTER. Infilco Inc., Model SW 1/8.

FIG. 6. SKID-MOUNTED DIATOMITE FILTER. Stoneheart Engineering Company, Model SF-X1.

FIG. 7. U. S. ARMY PORTABLE WATER PURIFICATION UNIT, MODEL 1940. Converted for use with diatomaceous silica.

FIG. 8. STANDARD 3000-GALLON CANVAS TANK WITH COVER.

was made up to 5 or 10 cc with distilled water, One-cc samples from these tubes were taken and mixed with one drop of one percent iodine in a Sedgwick-Rafter counting cell. The area of the chamber was examined by the use of the low (10x) and intermediate power (20x) objectives of a compound microscope. The amount of material examined was determined to a great extent by the amount of sediment present. All doubtful objects were recorded as cysts only when two observers were agreed as to their being cysts.

The testing program was scheduled as follows:

a. Tests with Standard Equipment

(1) Operation of U. S. Army Portable Water Purification Unit, Model 1940, at 15 gpm without Pretreatment. The first group of three tests was conducted on the portable sand filter to determine its efficiency in the removal of the amoebic cysts under several conditions of operation. An initial output of 15 gpm, representing a flow rate of 9.6 gpm per square foot of area, was used throughout this first group of tests. The three conditions represented were as follows:

(a) Filtration without treatment.

(b) Filtration with insufficient or improper coagulation.

(c) Filtration with good coagulation.

In each of these tests, the filter was operated until a schmutzdecke had been formed before the cysts were introduced in a batch through the pump suction. The period required to introduce the cysts and wash down the intake funnel did not exceed 30 seconds. The results show that, while the efficiency of the unit in removing amoebic cysts is somewhat proportional to the quality of the treatment, the removal of cysts of Endamoeba histolytica, even under ideal conditions, is not obtained when the unit is operated at 9.6 gpm per square foot.

(2) Operation of U. S. Army Portable Water Purification Unit, Model 1940, at 10 gpm without Pretreatment. The second series of tests consisted of two tests designed to determine the efficiency of the portable sand unit in removing amoebic cysts when operated at the output rate of 10 gpm. This output represents a flow rate of 6.35 gpm per square foot. In this series of tests, every available control was utilized to obtain ideal operating conditions for the tests. Cysts were introduced in a batch in the first test, whereas they were fed through the hypochlorinator at a uniform rate in the second test. A marked improvement was

noted in the efficiency of the unit in removing amoebic cysts over the results obtained at the higher flow rate.

(3) Operation of U. S. Army Portable Water Purification Unit, Model 1940, at 10 gpm Following Coagulation and Sedimentation. The third and final series of tests conducted with the portable sand filter consisted of three tests designed to determine the efficiency of pretreatment, followed by filtration, in removing amoebic cysts from water. In the first of these tests, cysts were introduced in the raw water and the water was allowed to settle without coagulants for one hour. The supernatant was then passed through the portable sand filter at the rate of 6.35 gpm per square foot. Microscopic examination of samples of both the settled water and the filter effluent indicated that settling for one hour without coagulants, while reducing the number of cysts present, does not remove cysts from water. The other tests of this series were conducted in like manner, with the exception that coagulants were employed, and in one case the detention period was extended to two hours. A marked reduction in the concentration of amoebic cysts by the process of coagulating and settling was noted.

b. Experiments with Diatomite Filters

(1) Experiment I-D, Stoneheart Engineering Company, Model SF-1. The purpose of this test was to determine the efficiency of diatomaceous silica in removing amoebic cysts from water. Because of the absence of previous studies of this material, the results could in no way be anticipated. Therefore, this test was in the nature of a trial run designed to act as a guide for further work with diatomaceous silica. For this test, 350,000 cysts of Endamoeba histolytica were added to one gallon of tap water to which clay had been added, the water was passed through the filter, and the entire gallon of effluent was subjected to microscopic examination. A complete absence of amoebic cysts in the effluent was noted. A grade of diatomaceous silica sold under the trade name of Sorbo-Cel by Johns-Manville, Inc., was used in the amount of 12.5 pounds per 100 square feet of filtering surface for the precoat. No slurry feed was used.

(2) Experiment 2-D, Wallace and Tiernan Company, Inc., Model G2. The filter-aid used in this test was a commercial product which had received a special treatment by the manufacturer of the filter. A precoat of this material was applied in an amount equivalent to 10 pounds per 100 square feet of filtering surface. A concentration of 6000 cysts per gallon was prepared in 50 gallons of Potomac River water and a uniform suspension maintained by agitation. The precoat was applied with the contaminated water. From the six gallons of effluent examined, three cysts were recovered.

(3) Experiment 3-D, S. F. Bowser and Company, Inc., Model 2MS. Using Potomac River water to which amoebic cysts had been added in the concentration of 6000 cysts per gallon, a precoat of Johns-Manville Celite Super-Cel was applied by recirculating the precoat water for a period of two minutes. The precoat of 3 ounces of the filter-aid was computed on the basis of 9.38 pounds per 100 square feet of filtering surface, while the body treatment was applied at the rate of 20 ppm, equivalent to 1 ppm of filter aid for each part of turbidity. A "break through" occurred after 8.25 minutes of filtering, following the loss of the pump suction. This allowed the flow to cease momentarily, thus dropping the cake. Subsequent testing, which is not a part of the work covered by this report, indicated that wire cloth elements such as are used in this unit are not generally satisfactory for the filtration of water. Prior to the "break through", no cysts were recovered from the effluent samples.

(4) Experiment 4-D, S. F. Bowser and Company, Inc., Model 1.5C. Tap water to which 25 ppm of chlorine had been added was recirculated through the unit for two minutes. The filter and water was then dechlorinated with sodium thiosulphate. Using this water, a precoat of Johns-Manville Sorbo-Cel was applied over a two-minute period. The precoat was computed on the basis of 10 pounds per 100 square feet of filtering surface. No body treatment was used. After precoating, the suction hose was changed to a tank of Potomac River water containing 10,000 cysts per gallon and the filtering cycle begun. After 11 minutes of filtering, the pump was stopped, and a slight back flow was introduced to facilitate the dropping of the precoat. Pumping was then resumed and the effluent discharged to waste for 50 seconds, at which time the effluent was again clear. No cysts were recovered from the effluent samples.

(5) Experiment 5-D, International Filter Company, Inc., Model SW 1/8. Using Potomac River water containing 6000 cysts per gallon, a precoat of Johns-Manville Sorbo-Cel was applied in the amount of 15 pounds per 100 square feet of filtering surface. After filtering for approximately 27 minutes at the initial rate of 2 gpm per square foot, the pump was stopped and the cake allowed to drop from the element. The pump was then restarted and the filter operated to waste for one minute. The flow rate was set at 4 gpm per square foot for this second phase of the test. No cysts were recovered from the effluent samples.

(6) Experiment 6-D, Naval Medical Research Institute, Model X. A precoat of Johns-Manville Sorbo-Cel in the amount of 36 pounds per 100 square feet was applied, using uncontaminated tap water. After precoating, 4110 cc of

Potomac River water, containing 10,000 to 12,000 cysts per gallon, were filtered. All of the effluent was collected and examined. No cysts were recovered. The procedure was repeated, using activated silver filter-aid in the amount of 15 pounds per 100 square feet. No cysts were recovered.

(7) Experiment 7-D, Stoneheart Engineering Company Model SF-XI. In view of the excellent results obtained with small units, tests on a larger scale were attempted. For this purpose the filter and precoat sections of the Model SF-XI were used in conjunction with the pumping section of a U. S. Army Portable Water Purification Unit. The precoat of Johns-Manville Sorbo-Cel was computed on the basis of 17 pounds per 100 square feet of filtering surface, and was applied by recirculating Potomac River water to which 225,000 cysts had been added. The amount of water required to fill the unit for recirculation was 35 gallons. Body treatment was applied during the run at the constant rate of 170 ppm, this rate being equivalent to 2.5 ppm of body treatment for each part of raw water turbidity. Cysts were applied through the hypochlorinator at the constant rate of 4500 cysts per gallon of influent. The engine stopped for no apparent reason after six minutes of filtering. Although the engine was restarted almost immediately, the presence of a quantity of diatomaceous silica in the effluent for approximately one minute after restarting indicated that some of the precoat had been disturbed by the slight reverse flow set up when the engine stopped. Of the 17 gallons of effluent examined, seven cysts were found in the samples taken during the early portion of the run.

(8) Experiment 8-D, U. S. Army Portable Water Purification Unit, Model 1940 Converted for Use with Diatomaceous Silica, (E. B. Model SFC-1). This unit was converted from a standard sand filter by personnel of the Engineer Board following, in general, the fundamental principles of the Stoneheart Engineering Company unit, Model SF-Xl. For this test a precoat of Johns-Manville Celite Sorbo-Cel was applied over a 3-minute period by recirculating 30 gallons of Potomac River water to which no cysts had been added. A secondary precoat consisting of one-half pound of Sorbo-Cel and one-quarter pound of Nuchar F.A.N. was then applied in like manner over a period of two minutes. The original precoat was computed on the basis of 15 pounds of filter-aid per 100 square feet of filtering surface. The body feed was regulated to give a constant addition of 120 ppm of filter aid, this being equivalent to 6 parts of body treatment for each part of raw water turbidity. The precoat was applied at the rate of 4.1 gpm per square foot of filtering surface while the filtering rate over the 25-minute run varied between 3.68 and 2.55 gpm per square foot. The cysts were applied at a constant rate of 3600 cysts per gallon. In the six gallons

of effluent examined, one cyst was found; this cyst appeared in the first five gallons of effluent.

(9) Experiment 9-D, U. S. Army Portable Water Purification Unit, Model 1940 Converted for Use with Diatomaceous Silica (E. B. Model SFC-1). This test was quite similar to Experiment 8-D, described above. A precoat of Johns-Manville Celite Sorbo-Cel was applied by recirculating 30 gallons of Potomac River water to which no cysts had been added. The precoat of one pound of filter-aid was calculated on the basis of 15 pounds of filter-aid per 100 square feet of filtering surface, and was applied at the rate of 2.5 gpm per square foot, while the filtering rate over the 25-minute run varied between 4.2 and 3.6 gpm per square foot. The body feed was regulated to maintain a minimum rate of pressure rise, 0.65 pound being used in the 25 minutes of operating time. The cysts were added at a constant rate of 1935 cysts per gallon of influent over the first 18 minutes of this operation, at the end of which time the supply of the organism was exhausted. In the six gallons of effluent examined, no cysts of Endameba histolytica were recovered.

(10) Experiments 10-D through 13-D, Inclusive, U. S. Army Portable Water Purification Unit, Model 1940. Converted for Use with Diatomaceous Silica (E. B. Model SFC-1). The majority of the tests with diatomaceous silica as outlined above were conducted with a grade of filter-aid sold by Johns-Manville under the trade name of Celite Sorbo-Cel. The purpose of these tests was to determine if the removal of amoebic cysts from water can be accomplished with all grades of material including the highest flow rate filter-aids available. The four filter-aids considered were Celite Super-cel, Hyflo Super-cel, Celite Sorbo-Cel and Celite 545 was processed by Johns-Manville. Both Celite Super-cel and Celite Sorbo-Cel were used in some of the tests previously discussed, Hyflo Super-cel is currently used by the British Army, and Celite 545 is one of the two highest flow rate materials available. With each filter-aid in turn, the precoat was applied at the rate of 15 pounds per 100 square feet of filtering surface. After precoating, the unit was then sterilized in each instance with sufficient chlorine to give an orthotolidine reading in excess of 100 ppm in the precoat water, dechlorinated with sodium thiosulphate, and checked for residual chlorine with orthotolidine. Filtration was then started, the cysts being added in a batch through the pump suction over a period of 30 seconds at the beginning of the filtering operation. One cyst was recovered from the effluent samples of each of the tests with Sorbo-Cel and with Hyflo Super-cel, whereas the results of the tests with Super-cel and with Celite 545 show that no cysts were recovered from the effluent

samples. It was noted that Celite 545 removed the cysts of Endamoeba histolytica notwithstanding the fact that the material is so coarse as to permit the passage of a considerable amount of turbidity.

IV. DISCUSSION

6. Objective. The objective of this study was to determine the efficiency of standard Army water purification equipment in removal of cysts of Endamoeba histolytica from water, and, in the event that present equipment proved unsatisfactory, to investigate the effectiveness of both new operating procedures and new types of equipment in removing amoebic cysts from water.

7. Background. Data are not available which permit an evaluation of the relative importance of water, as compared with other modes of transmission, in the dissemination of amoebic dysentery. In the United States, outbreaks of water-borne amoebiasis were recorded a decade ago. However, the absence of data in no way excludes the possibility of water being an important medium of transmission of amoebic dysentery under certain favorable conditions. The largest outbreak of amoebiasis known to have occurred was that in Chicago in 1933. It was thought that 160,000 persons were exposed to the infection by means of a contaminated drinking water supply; of this number it is known that 1,409 cases of the disease developed, with 98 fatalities. No concurrent cases of other infectious enteric diseases occurred in the exposed group, apparently because an adequate chlorine residual was maintained in the contaminated water supply to kill the pathogenic enteric bacteria. This water-borne epidemic shows clearly that severe infections can be acquired from the consumption of water lacking a noticeably disagreeable taste and odor. Bunker shows a hypothetical case that a chlorinated but unfiltered municipal water in Bogota, Colombia, might contain over 1,000 cysts of Endamoeba histolytica in each liter of distributed water. Thus a chlorinated water regarded as potable by the usual physical standards and bacteriological examinations can be responsible for infections with E. histolytica. The inherent difficulties of culturing E. histolytica and of differentiating it from free living amoebae have prohibited the isolation and, therefore, the enumeration of these organisms in raw water.

The degree of hazard of acquiring amoebiasis among troops cannot be evaluated at this time. It would appear that such an evaluation could be made only by detailed epidemiological methods that are difficult to use under combat conditions. Peacetime experience has taught that the strains of amoebae occurring in the Pacific and India-Burma-China theatres are particularly virulent, and that these amoebae are harbored by high proportions of the natives. The cysts must commonly be present in the surface waters of these areas. The potential threat of water-borne amoebiasis is further emphasized by the recent work of Brady, Jones, and Newton showing that practical dosages

of chlorine do not necessarily destroy the cysts of E. histolytica.

One of the most important requirements that a water purification unit must meet to be satisfactory for military use in the field is that the ratio of the quantity of water produced to the weight of the unit must be high. Of equal, and perhaps of greater, importance is the uncontested requirements that the water produced be both palatable and safe. With the use of sand as the filtering medium, experience has shown that the two requirements above are uncompromisingly opposed, one to the other. With few exceptions, the ratio of the weight of a sand filter to its filtering area is a fixed quantity of considerable magnitude. It is therefore necessary to resort to high flow rates to obtain a satisfactory ratio of output to weight. In civilian practice it has been found that flow rates of from two to three gallons per minute per square foot of filtering surface represent the maximum rates for satisfactory results. It will be noted that these flow rates are used only after carefully controlled pretreatment of the raw water. Present sand filters used by the armed forces of the United States are operated at flow rates varying between 6 and 10 gpm per square foot of filtering surface while handling raw water which has received inadequate pretreatment. It has been necessary with the use of sand, therefore, to sacrifice quality for greater output. The wisdom of permitting high flow rates in the sand filters now in use has been open to question for some time, but little or no testing has been previously conducted to evaluate the effect of these high flow rates on the quality of the water produced.

The use of diatomaceous silica as a filtering medium for water does not represent a new basic idea. Equipment for water filtration using Kieselguhr, an unrefined form of diatomaceous silica, was tested by the United States Army at Carlisle Barracks in 1938. The equipment at that time consisted of a canvas duck element on which the Kieselguhr was deposited. Both the Kieselguhr and the element available were not suitable for water filtration; hence, the equipment tested was not satisfactory. Since 1930, great strides have been made in the processing of diatomite. Methods have been developed to obtain filter aids having almost any desired characteristic, and at the same time increasing both the efficiency and flexibility of the material far beyond anything obtained with the original Kieselguhr. These materials are today being used in the filtration of such commercial products as paint, oil, sugar and alcoholic beverages. However, except in rare instances where filter-aid has been used to "polish" tap water, diatomaceous silica has not been used extensively for water filtration. One of the contributing factors to this condition has been the difficulty of obtaining an element possessing the necessary permeability, porosity, strength, and backwash characteristics for water filtration. Early in 1943, the Stoneheart Engineering Company (now merged with Titeflex, Incorporated) presented a pilot model filtering unit to the Engineer Board which apparently was reasonably satisfactory for water filtration. Using a special filter aid processed by Johns-Manville, this unit was tested at the laboratories

of the Engineer Board at Fort Belvoir, Virginia. This unit, among others, was used in the tests covered by this report.

Of particular interest is the development of diatomaceous silica filtration equipment overseas. Within the past decade, a unit known as the Stellar filter has been developed in England. This diatomaceous silica unit, constructed in several sizes, is now standard equipment in the British Army. There are indications that some of these units have been operated by American forces stationed in England. The Italians purchased some of the early units built in England, and it is possible that the equipment was used in the Ethiopian campaign. Stellar units, operated by Australian forces, have been used in the Southwest Pacific Area. Diatomaceous silica filtration equipment is used by both Canadian and New Zealand troops. Canadian troops have also used sand filters similar to the U. S. Army Portable Water Purification Unit, Model 1940. Filter aids used by the British are purchased in this country from Johns-Manville and from the Dicalite Company.

Because of the unprecedented requirements for filtration equipment for our widely dispersed forces in the Southwest Pacific Area, a number of diatomaceous silica units have been supplied to our forces. This filter, known as the Mollinite Filter, Model H51, was developed by the Fletcher Chemical Company (Aust.), Pty, Ltd., Victoria, Australia. While it is understood that this unit produces relatively good results, further development of the mechanical details appears to be necessary before the unit can be considered satisfactory for general field use.

8. Tests with Standard Equipment. The U. S. Army Portable Water Purification Unit, Model 1940, was used in the experiments conducted with sand filtration. It is logically assumed that the results obtained also apply to the U. S. Army Mobile Water Purification Unit, Model 1940, which, except in size, is similar to the smaller unit. The recommendations of this report relative to the mobile unit are based on this assumption.

a. Test I. Operation at Rated Capacity without Coagulants. (See Figure 9.) The significance of this test lies in the fact that cysts passed the filter in very large numbers, showing conclusively that the sand bed alone cannot be expected to remove cysts with operation at rated capacity. The water used in this test was obtained from the Fort Belvoir water supply and contained considerable iron from corroding mains.

b. Test II. Operation at Rated Capacity with Coagulants. (See Figures 10 and 11.) This test was conducted in such manner as to parallel methods currently used in the field. Water was pumped through the filter with the addition of coagulants in sufficient quantity to produce a "clear" effluent. The effluent pH was then determined and this pH maintained throughout the operation. A reasonably clear effluent was obtained, but the

total amount of water produced was low because the filter plugged rapidly. An after-floc was visible in the effluent during more than half of the operation, and the pH control was extremely difficult. The raw water, having very little buffering action, added to the difficulties in the use of color standards for pH control. It will be noted that cysts passed the filter during the first part of the operation in the same general order as in Test I, when no coagulants were used. No cysts were recovered at flow rates below 3 gpm per square foot. Cysts passed the filter with considerable ease while the effluent remained relatively clear. It is therefore apparent that removal of cysts is not necessarily a function of turbidity removal.

c. Test III. Operation at Rated Capacity with Coagulants. (See Figures 12, 13, and 14.) Every control feasible for field operation was employed in this test. The raw water was obtained from the Potomac River just prior to the test; jar tests were conducted to obtain the optimum coagulant dosage; pH determinations were made at one minute intervals; and the pump speed was not changed during the operation. Notwithstanding the attempt to provide ideal operating conditions and controls, cysts passed the filter. The increased turbidity and high plate counts in Samples 31, 32, and 33 indicate a break through of the filter bed after 25 minutes of the test operation. A close correlation is noted between effluent turbidity and bacterial removal, while cysts passed the filter in the greatest number when the effluent turbidity was lowest. The presence of after floc in Samples 31, 32, and 33 was due to insufficient time for complete flocculation ahead of the filter. At the output rate of 15 gpm, slightly more than one minute is available for floc formation before the water reaches the portable sand filter. The bacterial analysis shows that the quality of the effluent deteriorated throughout the operation with Sample 33 producing results not unlike the raw water. The effluent turbidity did not exceed 3 ppm at the filter. However, cysts passed the filter with ease and the bacterial analysis shows that nothing better than a crude straining job was accomplished.

d. Test IV. Operation at Reduced Rate with Coagulants. (See Figures 15, 16, and 17.) This test was conducted at the reduced rate of 10 gpm, equivalent to 6.35 gpm per square foot of filtering surface. The cysts were introduced in two batches, the first at the start of the operation and the second after 30 minutes. Cysts passed the filter, but the numbers passing were considerably changed from the results obtained in tests at rated capacity. At the time the second batch of cysts was applied, a Schmutzdecke of as much as one-halfpound of clay and coagulants had been built up on the filter. Cysts passed the filter at this time in equal or greater numbers than at the beginning of the test. Attention is called to the wide range of the pH values obtained with the Beckman instrument as compared with the values obtained with the color indicator at the unit. A comparison of effluent

turbidities at the unit and after 24 hours shows a considerable increase in effluent turbidity after standing. For the most part, this increase was due entirely to after floc. The presence of clay particles in Samples 38 and 39 indicated a break through in the filter bed. A marked increase in bacteria passing the filter accompanied this turbidity rise, while the number of cysts passing the filter was not materially changed. Here, as in previous tests, a reasonable effluent was maintained, bacteria removed to some degree, and a satisfactory output rate maintained, but cysts passed the filter with monotonous regularity.

e. Test V. Operation at Reduced Rate with Coagulants. (See Figures 18, 19, 20, and 21.) The purpose of this test was to determine the effect of adding the cysts continuously to the filter, and to determine the effectiveness of backwash in removing entrapped cysts from the unit. This test shows that the number of cysts passing the filter was changed somewhat by substituting continuous feed for batch application of the cysts. Samples 55, 56, and 57 are extremely interesting. After 20 minutes of the test, it was found that the output had fallen to slightly below 10 gallons per minute. The pump speed was increased slightly, resulting in an output of approximately 11 gallons per minute. This operation was carefully executed to minimize sudden impulses on the filter bed. Notwithstanding, a decided break through occurred immediately following this flow adjustment, with an increase in effluent turbidity, a sharp rise in bacteria, and, in this case, a rise in the number of cysts passing the filter being noted. The unit was backwashed with river water, to which no cysts had been added, for a period of five minutes at the rate of 20 gpm. Filtration was resumed as before with no additional cysts being applied. Sample 59, taken after eight minutes of filtering, contained 2.0 cysts per gallon of effluent. It is obvious that backwashing should be done with filtered water inasmuch as cysts in the backwash water can be caught within the sand bed during the operation. The rate of backwash should be the highest at which the sand does not escape the filter, probably about 25 gallons per minute.

f. Test VI-A. Sedimentation without Coagulants. (See Figures 22 and 23.) The purpose of this test was to determine the effectiveness of sedimentation without coagulants in removing cysts from water. It shows that while the total number of cysts per gallon of water is reduced, sedimentation for 90 minutes is not effective in removing either cysts or bacteria from water. Attention is directed to the fact that the effectiveness of sedimentation was based on the top portion of the settled water. (See Test VI-B.)

g. Test VI-B. Operation at Reduced Rate without Coagulants. (See Figures 24, 25, and 26.) This test parallels to some degree Test I in that water containing cysts was pumped onto the filter without coagulants. It differs in that the supernatant used from

Test VI-A contained a reasonably uniform number of cysts, while batch application of the cysts was used in the first test. In addition, it is possible that the cysts remaining in the supernatant of Test VI-A and used here contained only the smaller cysts. Cysts passed the filter in this test at a fairly uniform rate. The reduced flow rate of 6.35 gpm/ft^2 was used in this test, whereas the unit was operated at rated capacity in the earlier test. The raw water used was obtained from the Potomac River. This water contained an unusual turbidity composed of a very light, nonsettling material similar in appearance to undissolved lime particles. The pH was above the average for the stream.

h. Test VII-A. Coagulation, 2-Hour Settling. (See Figures 27 and 28.) It was the purpose of this test to coagulate and settle following, in general, methods used in the field, namely: determination of optimum coagulant dosage by a modified jar test and the addition of the coagulants to the water while pumping with use of the alum feed pot. The modified jar test used consists of filling a bottle or other container with raw water, adding a small amount of alum dissolved in water, and shaking violently for about one minute. Additional alum is added until a satisfactory floc is formed. At this point, the pH of the sample is determined. Pumping is then begun, with alum being applied through the feed pot in sufficient quantity to produce the same pH reading as was obtained in the jar test. This procedure was followed in this test with most unsatisfactory results. With approximately three feet of suction lift the coagulant feed through the unit was hopelessly erratic. After pumping 1288 gallons, it was found that 5.1 gr/gal of alum had been applied while the desired dosage was 10 gr/gal. The dosage applied would have been considerably lower if the second feet pot had not been used during a part of the operation. Since the floc formed was extremely fine, little or no settling occurred during the 60 minutes provided. A standard jar test was then conducted which showed that the dosage of 10 gr/gal of alum was satisfactory, but that 5 gr/gal of soda ash in addition considerably improved the size and settling quality of the floc. Hence 5 gr/gal of alum and 5 gr/gal of soda ash were dissolved in water and added to the tank of previously treated water. The soda ash and the alum were added in turn and distributed throughout the tank by agitation with a paddle. An excellent floc was formed as indicated by the settled water turbidity value of 2 ppm after 60 minutes of settling. Figure 27, Test VII-A, shows that better removal of cysts was accomplished in this test with coagulation and sedimentation than was accomplished by filtration at rated capacity in Tests II and III. It is to be noted, however, that samples 79 through 86 were taken from supernatant and that not more than 25 percent of the water depth was used in the subsequent filtration in Test VII-B. The results of Test VII-A are somewhat difficult to interpret because of the difficulty encountered in obtaining a satisfactory floc at the start of the operation. It is of considerable interest,

however, in view of the high degree of clarification accomplished, that cysts were found in each of eight small samples collected from the supernatant.

i. Test VII-B. Operation at Reduced Rate Following Coagulation and Sedimentation. (See Figures 29 and 30.) In this test the water which had been coagulated and settled in Test VII-A was pumped through the filter at the reduced rate of 6.35 gpm per square foot. The finding of several cysts in three of eight filter effluent samples shows that the efficiency of the unit in removing cysts from water is greatly improved by pretreatment of the raw water. Attention is directed to the clarity of the effluent which was consistently below 0.5 ppm and further that an output of 10 gpm was maintained without any increase in head loss.

j. Test VIII-A. Coagulation, 75-minute Settling. (See Figure 31.) This test was conducted for the purpose of determining the efficiency of coagulation and sedimentation in removing cysts from water. The method followed was one that could be followed in the field. A 60-gallon metal drum was placed upright in a 3000-gallon canvas tank and the water pumped into the drum. The coagulants were dissolved in water and these solutions introduced continually during pumping. Cysts were pumped through the hypochlorinator at a constant rate of 4300 cysts per gallon of water pumped. Using the metal drum as a flash mixer, an excellent floc was formed, which settled rapidly. Reduction in cysts due to coagulation and sedimentation for 75 minutes was reasonably good, the number per gallon being reduced from 4300 to less than 100. The results of this test show that while the number of cysts present in a quantity of water are materially reduced by a method of coagulation and sedimentation, suitable for field use, complete removal is not accomplished.

k. Test VIII-B. Operation at Reduced Rate Following Coagulation and Sedimentation. (See Figure 32.) In this test the water treated and settled in Test VIII-A was pumped through the portable sand filter at the reduced rate of 6.35 gpm per square foot. It is apparent from Figure 32 that the procedure followed produced excellent results in removing turbidity. The passage of cysts through the filter in water containing only 0.1 ppm turbidity emphasizes the apparent impossibility of removing cysts with the sand filter when operated at rates practical for field use.

l. Summary of the Indicated Number of Cysts Removed by the Portable Sand Filter under Several Conditions. (See Figure 33.) It will be noted that the efficiency of the unit varies somewhat proportionately with the coagulation achieved, the efficiency of the unit being highest when the control of the coagulation is best. The coagulant used in this equipment was ammonium alum applied through a differential pressure pot. The

contact time for floc formation ahead of the filter was quite short, there being but 10 feet of hose connecting the pump to the filter. The instructions for operating state that coagulants should be applied in sufficient quantity to produce a clear or satisfactory effluent. The result is that quite frequently a heavy after-floc forms in the effluent, while insufficient flocculation is obtained ahead of the filter. At present, "clear water" is determined by observation on the part of the operator. Experience dictates that equipment for making a jar test and a turbidimeter for checking the quality of the effluent should be a part of this equipment.

It will be noted from Figure 33 that two experiments were conducted using no coagulants. The results of these two experiments are not directly comparable because in the second experiment the filtration had been preceded by sedimentation and conceivably only the smaller cysts were present in the filter influent. The presence of considerable iron in the raw water of the first experiment may have acted as a floc, and assisted in the reduction of the number of cysts passing the filter. The significant feature of these two experiments is that it is convincingly demonstrated that sand alone does not remove the cysts of <u>Endamoeba histolytica</u> even at the reduced rate of 6.35 gpm per square foot. Hence, it follows that if cysts are to be removed from water with the portable sand filter, the removal must be accomplished by the coagulants alone or in combination with the sand.

A comparison of the experiments in which careful control of the coagulants was maintained shows that the reduction of the rate of flow by one third materially aided in the removal of cysts. Thus the number of cysts passing the filter was reduced from 3900 to 900 and 1400, respectively, in two experiments in which the rate of flow was reduced from 9.5 to 6.35 gpm per square foot. This reduction represents a fourfold increase in the efficiency of cyst removal. This reduction is consistent with the work of Baylis, Gullans, and Spector performed with a municipal type filter in which practically no cysts were found at the rate of 2.0 gpm per square foot. The microscopic examination of the effluent samples after sand filtration showed in each case that objects of sizes considerably larger than cysts passed the filter.

<u>m.</u> <u>Results with coagulation and Sedimentation</u>. (See Figure 34.) The results of experiments with pretreated water listed in Figure 34 show that the number of cysts in a given quantity of water is materially reduced by good coagulation and sedimentation, but that sedimentation alone for practical periods of time is of little value. It is obvious, therefore, that coagulation and sedimentation of the raw water is highly desirable before filtration through the sand filters. A second feature of coagulating and settling the raw water is that the resulting reduction in raw water turbidity materially reduces the tendency of

the filter to "break through" at frequent intervals. Prechlorinating the raw water prior to the addition of the coagulants tends to reduce tastes and odors, and generally enhances the possibility of producing a safe water.

9. Experiments with Diatomite Filters. The diatomite filters used in this study were experimental models, eight different units being used in all. It was anticipated that the numbers of cysts found in the effluent waters would provide a criterion for assessing the filtering efficiency of the types of equipment and filter aid tested. However, the results showed that with all equipment and filter aid tested, cysts were rarely found in the effluent water. It appears from these experiments that diatomaceous silica filtration is much more effective than sand filtration for the removal of cysts. This is further confirmed by the microscopic examination of the filtered water, in which it was very rare to find particles larger than 2 or 3 micra in diameter. Experiments I-D through VI-D were conducted with small units for the purpose of obtaining data concerning the general characteristics of diatomaceous silica filters in removing cysts from water, while the objective of the remainder of the experiments was to determine the efficiency of the material and equipment under conditions similar to those encountered in the field. The experiments conducted were as follows:

a. Experiment I-D. Stoneheart Engineering Company Model SF-1. (See Figure 35.) In this experiment, low pressure and flow rate was used; in general, the results were inconclusive. However, attention is directed to the high concentration of cysts used in the raw water and to the fact that from all of the effluent, no cysts were recovered. Since all of the water used was filtered, the filter was emptied with the fourth quart of water filtered, leaving the filter cake dry. The cake did not drop from the element when the flow ceased.

b. Experiment 2-D. Wallace and Tiernan Company, Inc., Model G2. (See Figure 36.) This experiment was conducted with a gravity filter equipped with a wire screen element. Good clarification was obtained, but a few cysts passed the filter. The element was observed to "breathe" under the influence of pressure variations. It is possible that the presence of cysts in samples 109 and 111 was caused by breaks in the cake because of slight pressure variations. However, the total number of cysts present was so small that the results obtained are inconclusive. During the experiment it was observed that a gravity type filter of this general type permits raw water to spill over in filling the reservoir, thus providing a possible means of contaminating the filter effluent as well as of bringing the operator in contact with the raw water.

c. Experiment 3-D. S. F. Bowser and Company, Inc., Model 2MS. (See Figure 37.) It will be noted from Figure 37 that no cysts were recovered from samples 112, 113, and 114 while a

large number were present in sample 115. This unit was equipped with a very short length of suction hose which was most difficult to keep submerged during the experiment. Just prior to collecting sample 115, air entered the suction hose for several seconds. The pump suction was thus momentarily interrupted, which interruption permitted the cake to break from the screen element. Subsequent filtering did not appear to replace the filter aid satisfactorily. It was noted that the differential pot slurry feeder supplied with this unit tended to clog at intervals.

d. Experiment 4-D. S. F. Bowser and Company, Inc., Model 1.5C. (See Figure 38.) This experiment was quite similar to Experiment 3-D. In Experiment 4-D the precoat was applied without recirculation by discharging the effluent to waste. Sample 117, collected after 1.5 minutes of operation, contained a small number of cysts, while sample 118, taken after 1.95 minutes, contained no cysts. This result indicates that precoating is accomplished with this unit in less than two minutes. With modifications in the inlet system used in Experiment 3-D, it will be noted that the cake was replaced without difficulty after it had been permitted to drop from the element. A comparison of the action of the carbon element to that of the wire screen element used in Experiment 3-D showed that the carbon element retained the cake better than the wire screen element. This may indicate that the carbon element would be the better of the two where variations in pressure, momentary shut-down and other disturbances are expected.

e. Experiment 5-D. International Filter Company, Inc., Model SW-1/8. (See Figure 39.) In that the equipment used in this experiment was a laboratory model, the results of this experiment should be interpreted with caution. The absence of cysts in the influent is significant.

f. Experiment 6-D. Naval Medical Research Institute, Model X. (See Figures 40 and 41.) The significance of this experiment is that it emphasizes the apparent ease with which cysts may be removed with simple devices employing diatomaceous silica as the filtering medium. Attention is directed to the second phase of this experiment in which activated silver filter-aid was used. It will be seen in Figure 40 that a marked reduction in bacterial count was accomplished with the special filter aid, but that B. coli was present in the effluent samples even when the plate count was sterile for 0.1 cc.

g. Experiment 7-D. Stoneheart Engineering Company, Model SF-X1. (See Figures 42, 43, and 44.) In this experiment the precoat was applied with water containing a large number of cysts. While the results obtained are inconclusive, Figure 42 shows that cysts are removed by equipment having sufficient capacity to be used in the field. Cysts were found in samples 129 and 130; thereafter, no cysts were recovered. The filter used in this

experiment was not constructed in a manner to permit easy venting of the air, with the result that the tubes did not properly precoat at the top. In addition, the engine stopped at time six minutes with some disturbance of the cake, as evidenced by the presence of silica in the effluent. Attention is directed to the increase in engine speed near the end of the operation. It was found that increasing the engine speed with the portable sand filter resulted in a "break through" of the filter media, while no difficulty was encountered with the diatomite unit because of pressure changes. Slurry was introduced through the pump suction during the operation.

h. Experiment 8-D. U. S. Army Portable Water Purification Unit, Model 1940, Converted for Use with Diatomaceous Silica (EB Model SFC-1). (See Figures 45 and 46.) This experiment was conducted with a standard sand unit converted by substituting three aloxite elements for the sand. The converted unit weighed 165 pounds as compared to 435 pounds for the sand filter. The results tabulated in Figure 45 show that no cysts were recovered except in the first sample. Since the effluent hose was used in precoating, the presence of cysts in the first sample may have been due to contamination of the effluent hose rather than to cysts passing the filter after the precoat was in place. Attention is directed to the use of carbon in this experiment. Because of the presence of considerable color in the water, a secondary precoat of carbon was applied at the start of the operation. Figure 46 shows that the carbon was retained on the original precoat, and the absence of any appreciable increase in turbidity after 24 hours shows that the color was removed satisfactorily. The influent pressure was maintained at eight pounds per square inch during the operation, with the exception of the last three minutes of the filter run when the influent pressure was increased to 13.5 pounds per square inch. The sudden rise in pressure did not disturb the operation in any manner. It will be noted that the average output during the operation was approximately 19.5 gpm.

i. Experiment 9-D. U. S. Army Portable Water Purification Unit, Model 1940, Converted for Use with Diatomaceous Silica (EB Model SFC-1). (See Figures 47 and 48.) This experiment differed from Experiment 8-D only in that activated carbon was omitted and that the pump was operated at full capacity from the beginning of the operation. The results tabulated show that the omission of carbon on the filter reduced the resistance and permitted higher flow rates. However, the marked increase in effluent turbidity after 24 hours indicates that color is not removed by the filter alone. The results show that total removal of cysts was accomplished during the operation at an average output of 25.9 gpm.

j. Experiments 10-D Through 13-D Inclusive. U. S. Army Portable Water Purification Unit, Model 1940, Converted for

Use With Diatomaceous Silica. (See Figures 49, 50, 51, and 52.) The purpose of this series of tests was to determine the effectiveness of various grades of diatomaceous silica in the removal of cysts from water. Attention is directed to the absence of cysts in quantity in the effluent from all of the materials tested. Since cysts were removed by all of the materials tested, the significant feature of these tests is that no cysts passed the unit in Experiment 13-D. The filter aid used in the experiment was Johns-Manville Celite 545, which is too coarse for water filtration. Notwithstanding the passage of turbidity in excess of 10 ppm no cysts were found in the effluent samples. Bacterial removal with the several grades of filter-aid tested is shown in Figure 53. It appears, therefore, that any currently manufactured filter-aid in the range of the materials tested will produce satisfactory results.

The test results indicate that diatomaceous silica filtration is much more effective than sand filtration for the removal of amoebic cysts. A filtration unit properly designed and operated would be expected to remove completely the cysts of *Endamoeba histolytica*.

It was not the objective of this study to develop diatomaceous silica filters, but rather to determine the efficiency of the material in removing cysts from water. However, during the tests the following design features were recognized as being essential for best results:

a. It appears that all diatomite filters should be provided with an air release cock which should be left open until the filter shell is entirely full of water at the start of the precoat operation.

b. In order to obtain an evenly distributed precoat, to obtain good initial clarity, and to prevent plugging the element with dirt, the elements should be so mounted as to permit the water in the filter to rise at least one inch above the top of the elements.

c. If the filter is precoated by recirculating a quantity of water, the water used should be filtered water and the piping arrangement should permit the change from precoating to filtering without interrupting the continuous flow of water. If recirculation is not employed, the precoat charge should be introduced directly into the filter shell.

d. There appears to be no definite relationship between the optimum rate of slurry feed and the turbidity (ppm) of the water filtered. The controlling factor in slurry feeding appears to be the nature of the raw water turbidity, water containing organic slimes requiring much more slurry than water containing only hard non-compressible particles.

e. Since the quality of the effluent from a diatomite filter is not necessarily a function of the pressure employed, it would appear that greatest efficiency would be realized when using pressures considerably in excess of those employed with sand filters.

f. The spent cake may be contaminated with amoebic cysts, cercariae, and other such organisms; hence, a cleaning or backwash method which does not bring the operator in direct contact with the waste material is necessary. The use of any but filtered water in backwashing should be prohibited, and the method used should not require the placing of the suction hose in the filtered water tank.

V. CONCLUSIONS

10. Conclusions. As a result of the study of the efficiency of standard army water purification equipment and of diatomite filters in removing cysts of *Endamoeba histolytica* from water, it is concluded that:

a. The complete removal of the cysts of *Endamoeba histolytica* is not accomplished with the sand filter of the U. S. Army Portable Water Purification Unit when operated at flow rates practical for field use, and it may be logically assumed that this condition applies also to the U. S. Army Mobile Water Purification Unit.

b. Sedimentation alone for short periods is not effective in removing amoebic cysts from water.

c. The total number of cysts in a given quantity of water is reduced by good coagulation and sedimentation.

d. Pressure type filters using diatomaceous silica as the filter medium will remove cysts of *Endamoeba histolytica*, provided the retaining membrane or element, as well as the filter shell, is correctly designed.

e. The combination of pretreatment, sedimentation, and filtration gives results considerably better than filtration alone.

VI. RECOMMENDATIONS

11. Recommendations. In view of the findings of this study of removal of cysts of *Endamoeba histolytica* from water, it is recommended that:

a. The output of the U. S. Army Portable Water Purification Unit, Model 1940, be reduced from 15 gallons per minute to 10 gallons

per minute as a maximum, and that this output be further reduced to not greater than 7.5 gallons per minute whenever possible.

b. The output of the U. S. Army Mobile Water Purification Unit, Model 1940, be reduced from 75 gallons per minute to 60 gallons per minute as a maximum, and that this output be further reduced to not greater than 45 gallons per minute whenever possible.

(It must be understood that this reduction in output rates is of an emergency nature and, while increasing the factor of safety, does not imply that complete removal of the cysts of *Endamoeba histolytica* is assured by adherence to the action recommended above.)

c. One hour of detention be provided for coagulating, settling and prechlorinating all raw water without exception prior to filtration through either of the sand units.

d. Field water quality control equipment be provided to all units in the field, which shall, among other things, provide equipment for conducting jar tests and for the evaluation of the overall efficiency of the filtration in terms of turbidity removal.

e. The study of diatomaceous silica now being conducted by the Engineer Board be continued to the end of determining the feasibility of the adoption of diatomaceous silica filtration equipment to replace the sand filters now in use.

f. Studies of the epidemiology of amoebic dysentery in the armed forces of the United Nations be encouraged, and reports from the field be examined to determine the magnitude of the part that water may be playing in the dissemination of amoebic dysentery.

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APPENDIX A

AUTHORITY

WAR DEPARTMENT
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON

SPESD   March 19, 1943

Subject: Study of the Effectiveness of Army Purification Methods in Removing Cysts of Endamoeba histolytica

To: The President,
The Engineer Board,
Fort Belvoir, Virginia

1. The Office of the Surgeon General has requested the Chief of Engineers to cooperate with the National Institute of Health in the study of the removal of the Cysts of Endamoeba histolytica from drinking water by means of standard Army purification equipment. This request has been approved with permission to contact the Engineer Board directly in this matter.

2. The Office of the Surgeon General has made an arrangement with the National Institute of Health to carry on certain studies of the epidemiology of amebiasis. This was done in accordance with a directive file number SPRMD 720.21, dated January 29, 1943 issued by the Commanding General, Services of Supply to the Medical Department. A copy of this directive has previously been sent to the Engineer Board.

3. It is therefore directed that the Engineer Board cooperate with the Surgeon General's office and the National Institute of Health in the program set up by them for the study of the Removal of the Cysts of Endamoeba histolytica. The cooperation of the Engineer Board is to be limited to that necessary to furnish properly filtered water as requested by the National Institute of Health.

By order of the Chief of Engineers:

/s/ E. L. Knutson,
/t/ E. L. KNUTSON,
Captain, Corps of Engineers,
Assistant, Engineering and Development Branch,
Supply Division.

Yarger:bg
EXT. 76271

APPENDIX B

TEST RESULTS DATA SHEETS

Fig. 9

Army Portable Water Purification Unit
Cyst Removal With Operation At Rated Capacity Without Coagulants
The Engineer Board and United States Public Health Service

Test Number I
Sheet 1 of 1

March 30, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. Turb. ppm	Cysts Recovered Per Gallon Per Million Applied	Operation	Remarks
-	0-20	12-15				-	Filtering	
-	0	15	5	2	-	-	"	1.4 million cysts applied in a batch through the pump suction.
1	2				1.0	1.790	"	
2	5				1.0	540	"	
3	10				1.0	117	"	
4	15	14.5	5	2	1.0	191	"	Gradual decrease in output noted
5	20				1.0	60	"	
6	25				1.0	83	"	
7	30				1.0	21	"	
8	35				1.0	12	"	
9	40				1.0	12	"	
10	45				1.0	5	"	
11	50	11	5	1.5	1.0	34	"	

Raw Water: Source: Belvoir Tap, Turbidity: 10/ p.p.m. pH: 7.6, Temperature: 52°F.
Treatment: Alum Applied: None, Soda Ash Applied: None, Other Treatment: None.

Procedure and Remarks: After operating the filter for 20 minutes, the output of the unit was adjusted to 15 gallons per minute. 1.4 million cysts of E. histolytica were then applied in a batch through the pump suction over a period of 30 seconds. The turbidity of the tap water used was due almost entirely to iron which may have acted as a floc, restricting the flow after 15 minutes of the test operation. The pump was set to maintain a constant discharge pressure throughout the operation. Total water filtered: 666 gallons.

Fig. 10

Army Portable Water Purification Unit
Cyst Removal With Operation At Rated Capacity With Coagulants
The Engineer Board and United States Public Health Service

Test Number II
Sheet 1 of 2

April 9, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. pH	Effl. Turb. ppm	Cysts Recovered Per Gallon Per Million Applied	Operation	Remarks
-	0-40	15-18					-	Backwash	Backwash with raw
-	0-20	12-15			6.6	1.0+	-	Filtering	water.
-	0	15	5	2	6.6	1.0+	-	"	2 million cysts
12	1				6.6	1.0+	398	"	applied in a batch.
13	2				-	1.0+	1,322	"	Effluent slightly
14	3				6.6	2.0	286	"	milky.
15	5				6.6	2.0+	232	"	Difficulty noted in
16	10	10	8	0	6.6	2.0	10	"	maintaining a constant
17	15	8.5			6.6	2.0	2	"	treated water pH. The
18	20	5.7	12	0	6.6	2.0	2	"	pH was adjusted to 6.6
19	25	5			6.6	1.0	1	"	just prior to the
20	30	-			6.6	1.0-	0	"	taking of each sample,
-	34	4			-	-	-	"	while variations
21	40	3			6.6	1.0-	0	"	between 6.4 to 6.8+
22	50	2.7	14.5	0	6.6	1.0-	0	"	were noted.

<u>Raw Water</u>: Source: Belvoir Tap and Clay, Turbidity: 50 ppm. pH: 7.5, Temperature: 53°F.
<u>Treatment</u>: Alum Applied: 1.6-1.7 gr/gal.. Soda Ash Applied: 1 gr./gal. (Discontinued after 5 min.)

<u>Procedure and Remarks</u>: After backwashing for 20 minutes using raw water, filtration was begun; the coagulants being varied until a satisfactory effluent was obtained. In that the use of soda ash did not improve the effluent, its use was discontinued at time 0-15 (elapsed time). The pH with the use of alum alone was found to be 6.6. Two million cysts of <u>E. histolytica</u> were applied in a batch through the pump suction at zero minutes over a period of 30 seconds. Total water filtered: 315 gallons.

Fig. 11

Army Portable Water Purification Unit
Cyst Removal With Operation At Rated Capacity With Coagulants
The Engineer Board and United States Public Health Service

Test Number II
Sheet 2 of 2

April 9, 1943

Sample Number	pH	Turbidity At Unit ppm	Turbidity 24 Hrs. ppm	Alkalinity MO ppm	Sulphates SO_4 ppm	Alum Dosage (Gr./Gal.) Calc. From Alkalinity	Alum Dosage (Gr./Gal.) Calc. From Sulphates	Appearance of Effluent	Sediment After 24 Hrs.
Raw	7.5	50	50	19.0	8.1	-	-		
12	7.3	1.0+	2.0	17.8	11.1	0.2	0.3	Slightly milky	Very slight
13	7.0	1.0+	1.5	10.0	20.3	1.8	1.6	Clear	None
14	6.8	2.0	3.0	6.8	27.6	2.4	2.7	Slightly milky	Moderate
15	6.8	2.0+	4.0	6.4	26.6	2.4	2.7	" "	"
16	6.9	2.0	3.0	9.4	19.7	1.9	1.6	" "	"
17	6.8	2.0	4.0	6.2	25.2	2.5	2.4	" "	"
18	6.9	2.0	3.0	9.0	18.8	2.0	1.4	" "	"
19	7.0	1.0	1.5	11.6	17.0	1.4	1.2	Clear	Slight
20	7.2	1.0-	1.0	12.2	14.6	1.3	0.9	Clear	None
21	7.2	1.0-	1.0-	12.2	15.2	1.3	0.9	"	None
22	7.2	1.0-	1.0-	12.8	22.4	1.4	1.9	"	None
						Av. 1.7	Av. 1.6		

Remarks: The alkalinity values tabulated above show that the effluent approached distilled water in its carbonate and bicarbonate content. This water would have very little buffering action and may account, in part, for the difference between the Beckman pH readings above and the readings with Bromthymol Blue made at the unit (Figure 10).

Fig. 12

Army Portable Water Purification Unit
Cyst Removal With Operation At Rated Capacity With Coagulants
The Engineer Board and United States Public Health Service

Test Number III
Sheet 1 of 3

April 16, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. pH	Effl. Turb. ppm	Cysts Recovered Per Gallon Per Million Applied	Operation	Remarks
-	0-11	16	8	0	-	-	-	Backwash	Discharged to waste.
-	0-8	15	5	2	6.4	-	-	Filtering	1.5 M cysts applied.
-	0	15	5	2	6.4	1-	-	"	Few particles of fine
23	3/4	15	5	2	6.4	1-	77	"	sand noted in effluent.
24	2	14.5	5	2	6.4	1-	50	"	
25	3	14.5	5	2	6.4	1-	10	"	
26	5	14	5	2	6.4	1-	8	"	
27	10	14	5	2	6.4	1-	3	"	
28	15	14	5	2	6.4	1.0	0	"	
29	20	13	5	2	6.4	1.0	3	"	
30	25	13	5	2	6.4	1.0	5	"	
31	30	13	5	2	6.4	2+	0	"	Effluent cloudy
32	40	13	5	2	6.4	2.0	0	"	" "
33	50	12	5	2	6.4	1-2	0	"	After floc noted
-	60	12	5	2	6.4	3+	-	"	" " "
-	61	17	8	0	-	-	-	Backwash	

Raw Water: Source: Potomac River, Turbidity: 50 p.p.m. pH: 7.2. Temperature: 48°F.
Treatment: *Optimum Coagulant Dosage: 2 gr./gal. (alum), Alum Applied: 2.0 - 2.2 gr./gal.

Procedure and Remarks: *Determined by standard jar test. The unit was backwashed and then operated with the addition of the coagulant for eight minutes during which time the effluent was run to waste. The output was then adjusted to 15 G.P.M. and 1.5 million cysts of E. histolytica were applied through the pump suction over a period of 30 seconds. Considerable care was exercised to maintain the pH of the treated water at the value of 6.4; readings and adjustments being made at one-minute intervals. Total water filtered: 647 gallons.

Fig. 13

Army Portable Water Purification Unit
Cyst Removal With Operation At Rated Capacity With Coagulants
The Engineer Board and United States Public Health Service

Test Number III
Sheet 2 of 3

April 16, 1943

Sample Number	pH	Turbidity At Unit ppm	Turbidity 24 Hrs. ppm	Alkalinity MO ppm	Sulphates SO_4 ppm	Alum Dosage (Gr./Gal.) Calc. From Alkalinity	Alum Dosage (Gr./Gal.) Calc. From Sulphates	Appearance of Effluent	Sediment After 24 Hours
Raw	7.2	50	50	37.2	9.1	-	-	-	Fine, flaky particles.
23	6.9	1-	3.0	27.4	22.5	2.1	1.8	Clear	Small amount of sand
24	6.8	1-	1.0	24.8	24.6	2.3	2.1	"	" " " "
25	6.8	1-	1.0	26.4	*	*	*	"	" " " "
26	6.7	1-	1.0	25.8	19.6	1.8	1.5	"	None
27	6.7	1-	1.0	27.2	25.1	2.2	2.1	"	Slight
28	6.8	1	1.5	25.8	29.9	2.3	2.9	"	Slight
29	6.7	1	1.5	26.2	29.7	1.9	2.8	"	Moderate
30	6.8	1	2.0	26.4	26.5	2.2	2.4	"	Moderate
31	6.7	2+	3.0	28.4	27.9	1.9	2.6	Cloudy	Much
32	6.9	2	3.0	28.2	25.0	2.0	2.1	"	Much
33	6.9	1+	3.0	30.6	24.1	1.8	2.1	"	
						Av. 2.0	Av. 2.2		

Remarks: *Sample broken. The appearance of the sediment after 24 hours found in samples 31, 32 and 33 indicated that a slight breakthrough had occurred. Attention is called to the increase in turbidity values both at the unit and after 24 hours in these samples. In addition to turbidity some after floc was noted in sample 31, 32, 33.

Fig. 14

Army Portable Water Purification Unit
Cyst Removal With Operation At Rated Capacity With Coagulants
The Engineer Board and United States Public Health Service

Test Number III
Sheet 3 of 3

April 16, 1943

Sample Number	Plate Count Nutrient Agar 20°C	LACTOSE BROTH 10 ml	1 ml	1/10 ml	1/100 ml	1/1000 ml	Turbidity At Unit (from Sheet 2)
RAW							
A	12,000	+	+	+	-	-	50
B	32,000	+	+	-	-	-	
C	30,000	+	+	+	-	-	50
D	18,000	+	+	+	-	-	
E	20,000	+	+	(+)	-	-	50
F	16,500	+	+	-	-	-	
G	24,000	+	+	-	(+)	-	50
H	20,000	+	-	-	-	-	
Av.	21,500						
23	24,000	- - -	- - -	- - -	-		1-
24	2,600	- - -	- - -	- - -	-		1-
25	3,800	- - (+)	- - -	- - -	-		1-
26	2,400	- - -	- - (+)	- - -	-		1-
27	3,800	(+)(+)(+)	- - -	- - -	-		1-
28	2,100	(+) + +	- - -	- - -	-		1
29	2,000	(+)(+) +	- - -	- - -	-		1
30	3,300	(+) + +	(+)(+)(+)	- - -	-		1
31	4,500	(+)(+) +	(+)(+)(+)	- - -	-		2+
32	7,600	+ + +	(+)(+)(+)	- (+) +	-		2
33	20,000	+ + +	+ + +	- (+) +	+		1+

Remarks: Samples A through H above represent samples taken from the raw water source at intervals during the operation. Samples marked thus (+) were negative after 24 hours but positive after 48 hours.

Fig. 15

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate With Coagulants
The Engineer Board and United States Public Health Service

Test Number IV
Sheet 1 of 3

April 27, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. pH	Effl. Turb. ppm	Cysts Recovered Per Gallon Per Million Applied	Operation	Remarks
-	0-20	18	6.5	1.0	-	-	-	Backwashing	Raw water used with
-	0-10	10	2.5	1.0	6.4	5.0	-	Filtering	no cysts added.
-	0	10	3.5	1.5	6.5	1.0-	-	"	2.5 million cysts
34	3/4	10	3.5	1.5	6.3	1.0-	0.8	"	applied in a batch.
35	2	10	3.5	1.5	6.5	1.0-	1.6	"	
36	3	10	3.5	1.5	6.5	1.0-	2.4	"	
37	5	10	3.5	1.5	6.5	0.8	3.2	"	
38	10	10	3.5	1.5	6.5	2	1.6	"	
39	15	10.5	3.5	1.5	6.4+	4	3.2	"	Alum dosage increased
40	20	10	3.5	1.5	6.4	0.5-	1.6	"	slightly to correct
41	30	9.5	3.5	1.5	6.4	1.0	0.0	"	increasing amount of
-	-	-	-	-	-	-	-	"	effluent turbidity.
42	32	9.2	3.5	1.5	6.4	1.0	0.0	"	2.5 million cysts
43	32-3/4	9.2	3.5	1.5	6.4	2.0	8.0	"	applied in a batch.
44	34	9	3.5	1.5	6.4	1.0-	3.2	"	
45	35	9	3.5	1.5	6.4	1.5	1.6	"	
46	37	9	3.5	1.5	6.4	1.5	9.6	"	

Raw Water: Source: Potomac River, Turbidity: 165 p.p.m. pH: 7.1, Temperature: 59°F,
Treatment: *Optimum Coagulant Dosage: 2.5 gr./gal. (alum), Alum Applied: 2.8 - 3.2 gr./gal.

Procedure and Remarks: *Determined by standard jar test. After backwashing, the unit was operated for ten minutes at 10 G.P.M. 2.5 million cysts of E. histolytica were then applied through the pump suction over a period of 30 seconds. At 32 minutes, 2.5 million cysts were applied in a batch through the pump suction in like manner to the first batch applied at the beginning of the test. Note: Turbidity of raw water due to a heavy rain. The turbidity for the most part consisted of relatively large particles. Total water filtered: 475 gallons.

Fig. 16

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate With Coagulants
The Engineer Board and United States Public Health Service

Test Number IV
Sheet 2 of 3

April 27, 1943

Sample Number	pH	Turbidity At Unit ppm	Turbidity 24 Hrs. ppm	Alkalinity MO ppm	Sulphates SO_4 ppm	Alum Dosage (Gr./Gal.) Calc. From Alkalinity	Alum Dosage (Gr./Gal.) Calc. From Sulphates	Appearance of Effluent	Sediment After 24 Hours
Raw	7.4	165	165	43	14.8	-	-	-	Very heavy
0	6.8	1.0-	-	20	45.4	4.4	3.7	Clear	Heavy after floc
34	6.7	1.0-	1.5	29	34.9	2.8	2.7	"	Slight
35	6.8	1.0-	1.5	32	25.7	2.2	1.4	"	Nil
36	6.9	1.0-	1.0	36	22.9	1.4	1.0	"	Slight
37	7.0	0.8	2.0	36	21.4	1.4	0.8	"	Slight
38	7.1	2.0	4.5	36	23.9	1.4	1.1	Milky	Moderate
39	-	4.0	8.0	16	54.3	5.4	4.8	"	Heavy
40	6.7	0.5-	1.5	18	50.1	4.6	4.2	Cloudy	Slight
41	7.0	1.0	2.0	32	29.9	2.2	2.1	"	Moderate
42	7.0	1.0	2.5	27	37.9	3.2	3.1	"	Slight
43	6.9	2.0	3.0	23	41.9	4.0	3.6	"	Moderate
44	6.8	1.0-	3.0	21	45.0	4.4	4.0	"	Moderate
45	6.8	1.5	2.5	21	44.5	4.4	4.0	"	Moderate
46	6.7	1.5	2.5	24	40.1	3.8	3.3	"	Moderate
						Av. 3.2	Av. 2.8		

Remarks: Attention is called to the range of the pH values above obtained with a Beckman instrument as compared with the pH values obtained at the unit (Figure 15) with the standard Bromthymol Blue color disc. The jar test conducted prior to this operation showed that 2 gr./gal. of alum gave a pinpoint floc while 3 gr./gal. gave a heavy floc. Attention is directed to the presence of after floc in the effluent notwithstanding the reduced flow rate.

Fig. 17

Army Portable Water Purification Unit
Cyst Removal With Operation at Reduced Rate With Coagulants
The Engineer Board and United States Public Health Service

Test Number IV
Sheet 3 of 3

Bacterial Analysis

April 27, 1943

Sample Number	Bacterial Count Per c.c. °C	Smallest Quantity Positive For B. Coli
Raw 0'	250	0.1 c.c.
Raw 10'	270	0.01 c.c.
Raw 20'	380	0.1 c.c.
Raw 30'	320	0.1 c.c.
0'	106	10.0 c.c.
34	10	0.1 c.c.
35	26	1.0 c.c.
36	24	1.0 c.c.
37	24	1.0 c.c.
38	188	1.0 c.c.
39	222	1.0 c.c.
40	14	10.0 c.c.
41	36	0.1 c.c.
42	43	0.1 c.c.
43	87	0.1 c.c.
44	165	1.0 c.c.
45	80	1.0 c.c.
46	325	1.0 c.c.

Fig. 18

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate With Coagulants
The Engineer Board and United States Public Health Service

Test Number V
Sheet 1 of 4

May 4, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. pH	Effl. Turb. ppm	Cysts Recovered Per Gallon Per Million Applied	Operation	Remarks
-	0-16	20	5	2	-	-	-	Backwashing	Raw water used
-	0-11	10	4	2	-	1+	-	Filtering	containing no cysts.
47	0	10	3.25	1	6.8	0.5	0.0	"	Addition of cysts
48	3/4	10	3.25	1	6.8	0.5-	0.0	"	through hypo-
49	2	10	3.25	1	6.8	0.5-	22.8	"	chlorinator begun.
50	3	10	3.25	1	6.8	0.5-	0.0	"	
51	5	10	3.25	1	6.8	0.5-	0.0	"	
52	10	10	3.25	1	6.8	0.5-	0.0	"	
53	15	10	3.25	1	6.8	0.5-	1.8	"	
54	20	9.5	4	1	6.6	0.5	1.4	"	Pump speed increased
55	30	11	4	1	6.8	4	3.7	"	to maintain flow at
56	40	10	3.5	1	6.7	3	9.9	"	10 g.p.m. Effluent
57	50	10	4	1	6.7	5	10.1	"	cloudy in samples
-					-	-	-	-	30,40, and 50.
-					-	-	-	-	
-	0-5	20	5	2	-	-	-	Backwashing	Raw water used
58	0	6.5	0.5	0	7.1	5+	0.0	Filtering	containing no cysts
59	8	9.5	2.75	1	6.7	1+	2.0*	"	*2.0 cysts per gal.
60	9	9.5	2.75	1	6.7	1+	0.0	"	Not cysts per gal.
61	10	10	2.75	1	6.8	1-	0.0	"	per million applied
62	11	11	3	1	6.8	1-	0.0	"	since none added
									after sample #57

Continued on Sheet 2.

Fig. 19

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate With Coagulants
The Engineer Board and United States Public Health Service

Test Number V
Sheet 2 of 4

May 4, 1943

Raw Water: Source: Potomac River, Turbidity: 120 p.p.m., pH: 7.1, Temperature: 58°F
Treatment: ** Optimum Coagulant Dosage: 2 gr./gal. (alum): Alum Applied: 2.3-2.4 gr./gal.

Procedure and Remarks: The unit was backwashed with raw water and then operated with alum for 11 minutes. Cysts of E. histolytica were applied through the hypochlorinator at the rate of 7,000 per gallon of effluent starting at zero minutes (Elapsed Time). After 50 minutes of operation, the unit was shut down, backwashed with river water to which no cysts had been added and operation resumed with no further addition of cysts. Samples were collected at intervals. ** Determined by standard jar test. Totaled water filtered: 504 gallons.

Fig. 20

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate With Coagulants
The Engineer Board and United States Public Health Service

Test Number V
Sheet 3 of 4

May 4, 1943

Sample Number	pH	Turbidity At Unit ppm	Turbidity 24 Hours ppm	Alkalinity MO ppm	Sulphates SO_4 ppm	Alum Dosage (Gr./Gal.) Calc. From Alkalinity	Alum Dosage (Gr./Gal.) Calc. From Sulphates	Appearance Of Effluent	Sediment After 24 Hours
Raw	7.1*	120	-	49.3	15.7	-	-	-	-
47	7.0	0.5	2.5	38.8	36.2	2.1	2.8	Clear	Slight
48	7.1	0.5-	1.0	40.4	26.1	1.7	1.2	"	None
49	7.1	0.5-	1.0	39.1	33.7	2.0	2.5	"	"
50	7.1	0.5-	1.0-	38.8	31.5	2.1	2.0	"	"
51	7.1	0.5-	1.0-	38.9	29.9	2.1	1.9	"	"
52	6.9	0.5-	1.0-	34.1	37.3	3.0	2.9	"	"
53	7.0	0.5-	1.0-	34.6	32.1	2.9	2.1	"	"
54	7.0	0.5	1.0	34.7	33.3	2.9	2.4	"	"
55	7.1	4	5.0	37.1	32.0	2.4	2.2	Milky	Moderate
56	7.1	3	4.5	37.3	34.8	2.4	2.6	"	Slight
57	7.0	5	7.5	35.0	35.6	2.8	2.8	Dirty	Heavy
					Av.	2.4	Av. 2.3		

Remarks: *pH reading with Bromthymol Blue. Turbidity in samples Nos. 55, 56, and 57 indicates definite "Break-through" of filter bed.

Fig. 21

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate With Coagulants
The Engineer Board and United States Public Health Service

Test Number V
Sheet 4 of 4

May 4, 1943

Bacterial Analysis

Sample Number	*Bacterial Count Per c.c. °C		Smallest Quantity Positive For B. Coli.
Raw 0'	180		0.1 c.c.
Raw 10'	4,300		0.1 c.c.
Raw 30'	5,000		0.1 c.c.
Raw 50'	2,400		0.1 c.c.
47	22	(absent)	10.0 c.c.
48	23		10.0 c.c.
49	25	(absent)	10.0 c.c.
50	20	(absent)	10.0 c.c.
51	42	(absent)	10.0 c.c.
52	190		10.0 c.c.
53	26		1.0 c.c.
54	38		1.0 c.c.
55	223		1.0 c.c.
56	102		0.1 c.c.
57	146		0.1 c.c.

* Agar count unreliable due to cloudy media.

Fig. 22

Army Portable Water Purification Unit
Cyst Removal By Sedimentation Without Use of Coagulants
The Engineer Board and United States Public Health Service

Test Number VI-A
Sheet 1 of 2

May 18, 1943

Sample Number	Elapsed Time Min.	Cysts Recovered Per Gallon of Supernatant	Operation	Remarks
-	0-41	10,000*	Pumping	Water being pumped into tank for
-	0-21	10,000	"	settling. Cysts applied through
-	0-1	10,000	"	hypochlorinator at rate of 10,000
-	0	-	Settling	cysts per gallon pumped
-	60	-	"	
-	90	-	"	End of settling period
-	90	-	Filtering	
63	95	557	"	See Test No. VI-B for filtering data.
64	100	1,552	"	
65	105	868	"	
66	110	656	"	
67	115	288	"	
68	120	1,056	"	
69	130	592	"	Less than half of the settled water had
70	140	1,232	"	been pumped through the filter at end of run.

Raw Water: Source: Potomac River, Turbidity: 50 p.p.m., pH: 7.8, Temperature: 70°F.
Treatment: Coagulants: None applied, Settled After Addition of Cysts: 90 minutes.

Procedure and Remarks: *Calculated from the rate at which the cysts were applied to the water through the pump of the hypochlorinator. 1230 gallons of water was pumped into a tank with the continuous addition of cysts at the rate of approximately 10,000 cysts per gallon of water. This was allowed to settle without the addition of coagulants for 90 minutes. The water used had been taken from the Potomac River May 18 and allowed to settle until the time of use. The turbidity of the water did not therefore decrease during the 90 minutes of settling used in this test. Attention is called to the magnitude of the drawdown in the tank during the subsequent filtering operation, the total being only 14 inches.

Fig. 23

Army Portable Water Purification Unit
Cyst Removal By Sedimentation Without Coagulants
The Engineer Board and United States Public Health Service

Test Number VI-A
Sheet 2 of 2

18 May 1943

<u>Bacterial Analysis</u>

Sample Number	Bacterial Count Per c.c. °C	Smallest Quantity Positive for B. Coli
Raw 0'	5,600	0.1 c.c.
Raw 20'	5,010	1.0 c.c.
Raw 40'	1,540	0.0001 c.c.
0'	8,250	0.01 c.c.
64	2,800	0.0001 c.c.
66	3,200	0.1 c.c.
68	1,200	0.1 c.c.
69	2,420	0.01 c.c.
70	2,940	0.001 c.c.

Fig. 24

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate Without Coagulants
The Engineer Board and United States Public Health Service

Test Number VI-B
Sheet 1 of 3

May 18, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. pH	Effl Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
*	90	10	4.5	2.5	7.8	10	-	Filtering	Discharged to waste
71	95	8	4.0	2.5	7.8	1.0	36	"	
72	100	11	7.5	4.5	7.8	2.0	256	"	Engine missing slightly
73	105	11	7.0	4.5	7.8	2.0	176	"	Valve adjusted at Time
74	110	10	6.0	4.0	7.8	1.0	174	"	106 to maintain flow at
75	115	10	6.7	4.5	7.8	1.0	168	"	10 g.p.m.
76	120	10	6.7	4.5	7.8	1.0-	174	"	
77	130	10	6.7	4.5	7.8	1.0	166	"	
78	140	10	6.6	4.5	7.8	1.0	198	"	End of test.

Raw Water: Source: Potomac River (settled water from Test No. VI-A), Turbidity: 50 p.p.m. pH: 7.8.
Temperature: 70°F,

Treatment: Water settled for 90 minutes (see Test No. VI-A), Coagulants Applied: None.

Procedure and Remarks: The filter was backwashed prior to the start of the run with Potomac River water to which no cysts had been added. Filtration was started without the use of coagulants at the output rate of 10 G.P.M. Total water filtered: 498 gallons.

Fig. 25

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate Without Coagulants
The Engineer Board and United States Public Health Service

Test Number VI-B
Sheet 2 of 3

May 18, 1943

Sample Number	pH	Alkalinity MO ppm	Turbidity At Unit	Appearance of Effluent	Sediment After 24 Hours
Raw*	7.8	62.5	50	Milky	-
71	7.8	60.0	1.0	"	Slight
72	7.7	60.0	2.0	"	"
73	7.7	60.0	2.0	"	"
74	7.7	60.0	1.0	"	"
75	7.7	60.0	1.0	"	"
76	7.7	60.0	1.0-	"	"
77	7.7	60.0	1.0	"	"
78	7.8	60.0	1.0	"	Very slight

Remarks: The turbidity of the water used was composed of very fine particles not unlike particles of lime. It will be noted that the alkalinity of the raw water is considerably above the average for the Potomac River at Gunston Cove. Average pH values for Potomac River water at this point 6.6 to 7.3.

* Raw water sample from supply tank collected before pumping into settling tank.

Fig. 26

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate Without Coagulants
The Engineer Board and United States Public Health Service

Test Number VI-B
Sheet 3 of 3

May 18, 1943

Bacterial Analysis

Sample Number	Bacterial Count Per c.c. °C	Smallest Quantity Positive For B. Coli
0	112,000	0.01 c.c.
72	110,000	0.0001 c.c.
74	3,750	0.1 c.c.
76	29,000	0.1 c.c.
77	8,000	0.01 c.c.
78	9,500	0.001 c.c.

Note: Attention is called to the very high counts in the effluent samples. This may be due to the filter becoming contaminated during the backwash operation.

Fig. 27

Army Portable Water Purification Unit
Cyst Removal By Coagulation and Sedimentation
The Engineer Board and United States Public Health Service

Test Number VII-A
Sheet 1 of 2

May 11, 1943

Sample Number	Elapsed Time Min.	Cysts Recovered Per Gallon of Supernatant	Operation	Remarks
-	0-46	3800	Pumping	Pumping was begun with the treatment section of the unit adding alum through the pot feeder.
-	0	3800	Settling begun.	
T60	60	-	Settling	Due to finess of floc which did not settle out, 5 gr./gal. alum and 5 gr./gal. soda ash was added to the tank of water and stirred with a paddle.
T120	120	-	Filtering begun	Discharge to waste.
-	123	-	Filtering	See Test Number VII-B for filtering data
79	128	3.2	"	
80	133	9.6	"	
81	138	6.4	"	
82	143	6.4	"	
83	148	1.6	"	
84	153	1.6	"	
85	163	4.8	"	
86	173	9.6	"	

Raw Water: Source: Potomac River, Turbidity: 50 ppm, pH: 7.4, Temperature: 72°F.
Treated Water: pH: 7.0*, Average Turbidity: 2 ppm.
Treatment: Coagulants: 5 gr./gal. alum followed in 60 minutes by an additional 5 gr./gal. alum and 5 gr./gal. soda ash. Water settled for total time of 120 minutes.

Procedure and Remarks: 1288 gallons of water was pumped into a tank through a treatment section of the unit with the addition of approximately 5 gr./gal. of alum being fed through the feed pots. A very fine floc was formed, which did not settle out in 60 minutes. Additional coagulants were added and another hour of settling time provided. Cysts were added continuously during the pumping operation at the rateof 3800 cysts per gallon of effluent. See Test No. VII-B for filtering data. *Bromthymol Blue reading.

Fig. 28

Army Portable Water Purification Unit
Cyst Removal By Coagulation and Sedimentation
The Engineer Board and United States Public Health Service

Test Number VII-A
Sheet 2 of 2

May 11, 1943

Sample Number	pH	Turb. ppm	Alkalinity MO ppm	Sulphates SO_4 ppm	Alum Dosage (Gr./Gal) Calc. From Alkalinity	Calc. From Sulphates	Remarks
Raw	7.7	50	51.1	26.2	-	-	Both alkalinity and pH high for
0-36	6.5	50	27.0	59.0	4.8	4.5	Potomac River water.
0-26	6.5	50	28.2	57.7	4.5	4.3	
0-16	5.5	50	3.4	102.2	9.5	10.4	Alum dosage increased by use of
0-6	6.1	50	10.2	84.4	8.1	8.0	second pot.
	6.2	50	14.5	79.5	7.3	7.2	
T 60	8.5	45	71.6	63.7	-	5.1	5 gr./gal alum and 5 gr./gal soda
T 120	7.2	2	54.1	103.2	-	10.6	ash applied.

Remarks: Samples Nos. 0-36 through 0-6 were taken from the discharge hose of the pump during the time of filling the tank for settling. When the additional alum and soda ash was added, the coagulants were first dissolved in water and applied to the top of the tank of water. The water was then agitated for 5 minutes with paddles. Sample No. T 60 was collected just prior to the addition of 5 gr./gal. of alum but after the addition of the soda ash.

Fig. 29

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate Following Coagulation and Sedimentation
The Engineer Board and United States Public Health Service

Test Number VII-B
Sheet 1 of 2

May 11, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press. psi	Effl. Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-								
T-120	120	10	3.0	0			Filtering	Discharge to waste.
-	123	10	2.8	1	0.5		"	
87	128	9.5	2.8	1	0.5	0	"	First sample collected.
88	133	10	3.5	1	0.5	2	"	Flow adjusted at Time
89	138	10	3.5	1	0.5	2	"	130
90	143	10	3.5	1	0.5	0	"	
91	148	10	3.5	1	0.5	0	"	
92	153	10	3.5	1	0.5	0	"	
93	163	10	3.5	1	0.5	0	"	
94	173	10	3.5	1	0.5	4	"	End of test.

Raw Water: Source: Coagulated and Settled (Test No. VII-A)., pH: 7.0, Turbidity: 2 p.p.m. (average).
Treatment: See Test Number VII-A

Procedure and Remarks: Potomac River water coagulated and settled in Test No. VII-A was pumped through the sand filter at the output rate of 10 g.p.m. Just prior to the operation, the filter was backwashed with tap water for five minutes at the rate of 20 g.p.m. In that the treatment section of the unit was known to be contaminated, an auxiliary pump was used to supply the filter during the operation.
Total Water Filtered: 495 Gallons.

Fig. 30

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate Following Coagulation and Sedimentation
The Engineer Board and United States Public Health Service

Test Number VII-B
Sheet 2 of 2

May 11, 1943

Sample Number	pH	Turbidity At Unit	Turbidity After 24 Hrs.	Alkalinity MO ppm	Appearance Of Effluent	Sediment 24 Hours
T-120	7.2	2	-	54.1	-	-
87	7.2	0.5	2	53.9	Cloudy	Moderate*
88	7.2	0.5	0.5	53.9	Clear	None
89	7.2	0.5	0.5	53.9	"	"
90	-	0.5	0.5	53.9	"	"
91	7.2	0.5	0.5	53.9	"	"
92	-	0.5	0.5	53.9	"	"
93	7.2	0.5	0.5	53.9	"	"
94	7.2	0.5	0.5	53.9	"	"

Remarks: *Sediment probably due to debris in lines rather than turbidity passing the filter.

Fig. 31

Army Portable Water Purification Unit
Cyst Removal By Coagulation and Sedimentation
The Engineer Board and United States Public Health Service

Test Number VIII-A
Sheet 1 of 1

June 29, 1943

Sample Number	Elapsed Time Min.	Cysts Recovered Per Gallon of Supernatant	Operation	Remarks
-	0-43	4300	Pumping	Water being pumped into tank for coagulation.
-	0	4300	Settling	Cysts applied continuously through hypochlorinator
-	75		"	at rate of 4300 cysts per gallon of water pumped.
TO	75	-	Filtering	Discharged to waste.
95	77	121	"	First sample collected.
96	87	-	"	See Test Number VIII-B for filtering data.
97	97	57	"	
98	107	-	"	
99	117	5	"	
100	127	-	"	
101	147	-	"	
102	149	43*	"	
103	152	-	"	
104	162	43*	"	Total water filtered: 850 gallons.

Raw Water: Source: Potomac River, Turbidity: 30 p.p.m. pH: 7.4, Temperature: 74°F.
Treated Water: pH: 6.7, Average Turbidity: ppm.
Treatment: Coagulants: 10 gr./gal. alum and 5 gr./gal. soda ash, Settled after addition of cysts: 75 Min.

Procedure and Remarks: 2200 gals. of water was pumped into a standard 3000-gallon canvas tank through the treatment section with the cysts being added continuously at rate of 4300 through the hypochlorinator. The pump effluent was directed into a drum set within the tank and the coagulants added continuously to the water. After the tank was full, the water was allowed to settle for 75 minutes before filtration was begun. *Combined sample.

Fig. 32

Army Portable Water Purification Unit
Cyst Removal With Operation At Reduced Rate Following Coagulation and Sedimentation
The Engineer Board and United States Public Health Service

Test Number VIII-B
Sheet 1 of 1

June 29, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
T-0	75	10.0	-	-	-		Filtering	Discharge to waste.
95	77	10.0	3.0	2.0	0.1	5	"	
96	87	9.7	3.0	2.0	0.1	4	"	
97	97	9.2	3.0	2.0	0.1	2	"	
98	107	9.4	3.5	2.0	0.1	0	"	
99	117	10.2	3.6	2.0	0.1	1	"	Rate adjusted at Time 109
100	127	10.1	3.8	2.0	0.1	1	"	Suction hose lowered to
101	147	9.8	3.8	2.0	0.1	5	"	within 3 inches of tank
102	149	-	-	-	-			bottom at Time 143.
103	152	9.8	3.8	2.0	0.2	1	"	
104	162	10.1	3.8	2.0	0.1	1	"	

Raw Water: Source: Coagulated and Settled (Test VIII-A), pH: 6.7, Turbidity: 70 p.p.m. (Average)
Treatment: See Test Number VIII-A

Procedure and Remarks: Potomac River water coagulated and settled in Test No. VIII-A was pumped through the sand filter at the output rate of 10 g.p.m. Samples were collected for microscopic examination at intervals. Attention is called to the increase in the number of cysts passing the filter at Time 147 following the lowering of the suction hose in the tank at Time 143. Just prior to this run, the filter was backwashed for 5 minutes with tap water at the rate of 18 g.p.m. Total water filtered: 850 gallons.

Fig. 33

Army Portable Water Purification Unit
Summary of The Results of Experiments With Operation Under Several Conditions
The Engineer Board and United States Public Health Service

Experiment Number	Quality of Coagulation	Filtration Rate GPM/ft.^{2}	Calc. Number of Cysts per Gal. Influent	Calc. Number of Cysts per Gal. Effluent	Cysts Passing Filter Per Million Applied
I	None	9.5	2100	250	119,000
II	Poor	9.5	6300	240	38,000
III	Good	9.5	2300	9	3,900
IV	Good	6.35	5000	4.5	900
V	Good	6.35	7000	10	1,400
VI-B	None	6.35	838	165	197,500

Fig. 34

Army Portable Water Purification Unit
Summary of the Results of Experiments with Operation
At Reduced Rate Following Coagulation and Sedimentation
The Engineer Board and United States Public Health Service

Experiment Number	Pretreatment	Settling Time (Min.)	Filtration Rate GPM/ft^2	Calc. Number of cysts per Gal. Influent	Calc. Number of Cysts Per Gal. Effluent	Cysts Passing Filter Per Million Applied
VI-A	None	90	-	10,000	838	83,800
VI-B	-	-	6.35	838	165	197,500
					Combined Results	16,500
VII-A	Alum ≁ Soda Ash	120	-	3800	5.4	1400
VII-B		-	6.35	5.4	0.95	176,000
					Combined Results	250
VIII-A	Alum ≁ Soda Ash	75	-	3800	56	14,700
VIII-B			6.35	56	2	35,700
					Combined Results	526

Fig. 35

Diatomaceous Silica Filter, Model SF-1
Cyst Removal with Gravity Type Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 1-D
Sheet 1 of 1

April 9, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press. psi	Effl. Press. psi	Effl. Turb ppm	Cysts Recovered Per Gallon Per Million Applied	Operation	Remarks
-	0-1.66	0.15	0.4	0.0	-	-	Precoating	First quart of effluent
-								returned to reservoir for
-								refiltering.
-	0	-	0.4	0.0	1-**	-	Filtering	
105	2.41	0.104	0.4	0.0	1-	0.0	"	First quart collected.
106	5.00	0.050	0.3	0.0	1-	0.0	"	Second quart collected.
107	7.91	0.031	0.3	0.0	1-	0.0	"	Third quart collected.
108	13.0	0.019	0.2-0.0	0.0	1-	0.0	"	Fourth quart collected.

Raw Water: Source: Belvoir tap and Clay, Turbidity: 50 p.p.m. pH: 7.5, Temperature: 53°F.
Treatment: Precoat: 0.25 oz. Sorbo-cel*, Slurry feed: None.

Procedure and Remarks: 350,000 cysts were added to one gallon of water. To about one quart of this suspension, 0.25 ounces of diatomaceous silica were added and this poured into the filter reservoir. The first quart of effluent was returned to the reservoir of the filter. The entire gallon was then filtered and the four quarts of effluent examined for cysts. *Precoat of 0.25 ounces is equivalent to 12.5 pounds of filteraid per 100 square feet of filtering surface. Area of filter approximately 0.125 square feet. ** Effluent turbidity of less than 1.0 p.p.m. is estimated.

Fig. 36

Diatomaceous Silica Filter, Model G-2
Cyst Removal With Gravity Type Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 2-D
Sheet 1 of 1

June 22, 1943

Sample Number	Elapsed Time Min.	Total Water Filtered Gallons	Infl. Press. psi	Effl. Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-4	-	1.3	-	-	Precoating	Effluent re-
-	0	0	1.3-1.0	0.5-	-	Filtering	turned to
109	3.58	5	1.3-1.0	0.3	0.5	Filtering	reservoir until
110	9.33	5	1.3-1.0	0.2	0.0	Filtering	clear
111	17.66	5	1.3-1.0	0.2	1.0	Filtering	
	Total	15					

Raw Water: Source: Potomac River, Turbidity: 20 ppm, pH: 7.4 Temperature: 72°F
Treatment: Precoat: Special filteraid (10 lb/100 ft.^{2}), Slurry Feed: None

Procedure and Remarks: The precoat was applied by recirculating contaminated water (6000 cysts/gal) to which the filteraid was added. The variations in influent pressure are due to changes in water level in the reservoir between the times of adding raw water from a bucket.

Fig. 37

Diatomaceous Silica Filter, Model 2MS
Cyst Removal With Hand Operated Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 3-D
Sheet 1 of 1

June 22, 1943

Sample Number	Length of Time Required to Collect Sample (Min. & Sec.)	Size of Sample (Gallons)	Number of Cysts Recovered	Calc. Number of Cysts Per Gallon (Effl.)	Operation
-	2:00	-	-	-	Precoating
112	2:35	5	0	0	Filtering
113	2:40	5	0	0	Filtering
114	3:00	5	0	0	Filtering
115	1:00 (approx.)	3.5	2*	114	Filtering
116	-	4	3	3.7	Filtering

Raw Water: Source: Potomac River. Turbidity: 20 ppm. pH: 7.4.
Temperature: 72°F.

Treatment: Precoat: JM Super-Cel. Slurry Feed: Charge of 3 oz.

Procedure and Remarks: The precoat was applied by recirculating contaminated water (6000 cysts 1 gal.) to which the filteraid had been added. *Air entered suction hose just prior to taking this sample. A small amount of slurry feed was applied during the run in accordance with recommendations of the manufacturer. The slurry feed was in the amount of 1 p.p.m. slurry per part of turbidity.

Fig. 38

Diatomaceous Silica Filter, Model 1.5C
Cyst Removal With Hand Operated Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 4-D
Sheet 1 of 1

July 16, 1944

Sample Number	Time at Beginning of Collection of Sample (Min. and Sec.)	Size of Sample (Gals.)	Number of Cysts Recovered	Calc. Number of Cysts Per Gallon (Effl.)	Operation
-	0	-	-	-	Discharge to waste
117	1:30	1	1	5	Filtering
118	1:57	5	0	0	Filtering
119	4:00	5	0	0	Filtering
-	10:00	-	-	-	Dropped cake
-	12:00	-	-	-	Discharge to waste
120	13:50	5	0	0	Filtering

Raw Water: Source: Potomac River, Turbidity: 100 p.p.m., pH: 7.4,
Temperature: 74°F

Treatment: Precoat: JM Sorbo-Cel (0.1 lb/100 ft^2), Slurry Feed: None

Procedure and Remarks: The precoat was applied with contaminated water (10,000 cysts/gal.) by discharging the first effluent to waste. After filtering for 10 minutes, the cake was dropped, replaced and filtering resumed.

Fig. 39

Diatomaceous Silica Filter, Model SW 1/8
Cyst Removal With Experimental Stellar Filter
The Engineer Board and United States Public Health Service

Experiment Number 5-D
Sheet 1 of 1

June 22, 1943

Sample Number	Length of Time Required to Collect Sample (Min. and Sec.)	Size of Sample (Gallons)	Number of Cysts Recovered	Calc. Number of Cysts Per Gallon (Effl.)	Operation
-	2:00	-	-	-	Precoating
121	26:55	5	0	0	Filtering
	-	-	-	-	Dropped cake
	2:00	-	-		Filter to waste
122	7:45	5	0	0	Filtering

Raw Water: Source: Potomac River, Turbidity: 20 ppm, pH: 7.4, Temperature: 72°F.
Treatment: Precoat: JM Sorbo-Cel, Slurry Feed: None.

Procedure and Remarks: The precoat was applied in the first instance by recirculating contaminated water (6000 cysts/gal.) for 2 minutes after which the unit was operated for approximately 27 minutes at 2 g.p.m./ft^2. The unit was then shut down and the cake allowed to drop. The unit was started, the cake replaced and the unit operated until a second sample of 5 gallons had been collected.

Fig. 40

Diatomaceous Silica Filter, Model X
Cyst Removal With Gravity Type Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 6-D
Sheet 1 of 2

August 10, 1943

Sample Number	Time at Beginning of Collection of Sample Min.	Size of Sample c.c.	Fraction of Sample Examined	Number of Cysts Recovered	Bacterial Count per c.c.	Smallest Quantity Positive for B. Coli
Raw	-	-	-	-	4600	0.1 c.c.
			Filtration with Sorbo-Cel			
123	0.00	450	all	0	-	-
123-B	0.50	-	-	-	1900	0.1 c.c.
124	1.00	1950	all	0	-	-
124-B	3.00	-	-	-	240	1.0 c.c.
			Further filtration after refilling bag			
125	0.00	410	all	0		
125-B	0.50	-	-	-	860	0.1 c.c.
126	0.66	2300	all	0	-	-
126-B	3.00	-	-	-	940	1.0 c.c.

Raw Water: Source: Potomac River. Turbidity: 50 ppm. pH: 7.4. Temperature: 78°F.

Procedure: The precoat of 0.2 pounds of Sorbo-Cel was applied by passing 3 quarts of clear tap water and filteraid through the filter, followed by a small quantity of river water to which no cysts had been added. After precoating 3 quarts of river water containing 10,000 - 12,000 cysts per gallon was filtered. The flow was started (zero minutes) and all water filtered was collected for examination. The bag was refilled with cyst-containing water and again all water filtered was collected for examination.

Fig. 41

Diatomaceous Silica Filter, Model X
Cyst Removal With Gravity Type Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 6-D
Sheet 2 of 2

August 10, 1943

Sample Number	Time at Beginning of Collection of Sample Min.	Size of Sample c.c.	Fraction of Sample Examined	Number of Cysts Recovered	Bacterial Count per c.c.	Smallest Quantity Positive for B. Coli
Raw	-	-	-	-	4600	0.01 c.c.
Filtration with activated silver-filteraid						
127	0.00	55	all	0	(Sterile 0.1 c. c.)	1.0 c.c.
128	1.00	750	all	0	-	-
128-B	2.00	-	-	-	10	1.0 c.c.

Raw Water: Source: Potomac River. Turbidity: 50 ppm. pH: 7.4. Temperature: 78°F.

Procedure: The apparatus was rinsed and 1 quart of water and 0.4 gms of the activated silver-filteraid combination were added. The unit was not precoated by recirculation, the first water being taken for examination.

Fig. 42

Diatomaceous Silica Filter, Model SF-X1
Cyst Removal With Pressure Type Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 7-D
Sheet 1 of 3

May 25, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-6	24.5	-	-	-	-	Precoating	Water recirculated.
129-A	0	23	16	3	0.5-	-	Filtering	Engine speed erratic.
129	5	21	16	3	0.5+	1.0	Filtering	Engine stopped for
130	10	15	15.5	0	0.04	1.7	Filtering	30 seconds at Time 6.
131	15	12.5	16	0	0.04	0.0	Filtering	
132	20	11	16	0	0.04	0.0	Filtering	
133	25	11	16	0	0.04	0.0	Filtering	
134	30	10.5	17	0	0.04	0.0	Filtering	Engine speed advanced
135	40	14	21	0	0.04	0.0	Filtering	at Time 32 min. and
136	50	12	25	0	0.5-	0.0	Filtering	again at Time 45 min.

Raw Water: Source: Potomac River, Turbidity: 65 p.p.m. pH: 7.6. Temperature: 68°F.
Treatment: Precoat: 1.5 pounds Sorbo-Cel*, Slurry Feed: 170 p.p.m.

Procedure and Remarks: 24 ounces of Sorbo-Cel and 225,000 cysts were added to 35 gallons of raw water. This suspension was recirculated through the unit for 6 minutes; at which time the effluent was relatively clear. Filtration was then started with the continuous addition of cysts and filteraid for a period of 50 minutes. The cysts were applied through the hypochlorinator at the constant rate of 71,500 cysts per minute. Attention is called to the relatively high influent pressure at the start of the test. This was due to excessive losses in the piping rather than to high resistance through the filtering cake. Total water filtered: 696 gallons. *Precoat of 1.5 pounds equivalent to 17 pounds per 100 square feet of filtering area.

Fig. 43

Diatomaceous Silica Filter, Model SF-X1
Cyst Removal With Pressure Type Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 7-D
Sheet 2 of 3

May 25, 1943

Sample Number	Effl. pH	Effluent Turbidity (ppm) St. Louis At Unit	Baylis After 24 Hrs.	Tindall After 24 Hrs.	Alkalinity MO ppm
Raw	7.6	-	-	-	34.7
129	7.6	0.5-	1.0	1.0+	34.7
130	7.6	0.5+	1.0	1.0	34.7
131	7.6	0 +	0.5-	0.5	34.7
132	7.6	0 +	0.5-	0.4	34.7
133	7.6	0 +	0.5-	0.3	34.7
134	7.6	0 +	0.5-	0.4	34.7
135	7.6	0 +	0.5-	0.3	34.7
136	7.6	0.5-	0.5-	0.2	34.7

Fig. 44

Diatomaceous Silica Filter, Model SF-X1
Cyst Removal With Pressure Type Silica Filter
The Engineer Board and United States Public Health Service

Experiment Number 7-D
Sheet 3 of 3

May 25, 1943

Bacterial Analysis

Sample Number	Bacterial Count Per c.c. 37°C	Smallest Quantity Positive for B. Coli
Raw*	1700	0.1 cc
129-A	29400	(absent)10.0 cc
130	4520	10.0 cc
132	4400	10.0 cc
134	2200	1.0 cc
135	390	(absent)10.0 cc
136	765	10.0 cc

Remarks: *Average of 6 samples taken at 10-minute intervals. Effluent hose and piping was not sterilized prior to the operation.

Fig. 45

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experiment Number 8-D
Sheet 1 of 2

June 8, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. Turb. psi	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-10	27.5	7	4	-	-	Precoating	Water recirculated
-	0- 7	27	8	4	-	-	Added carbon	Water recirculated
137	0	24.5	8	4	0/	1	Filtering	
138	5	21	8	3	0/	0	Filtering	
139	10	18	8	3	0/	0	Filtering	
140	15	18	8	3	0/	0	Filtering	
141	20	14	8	2	0/	0	Filtering	Pump speed increased
142	25	17	13.5	3	0/	0	Filtering	at Time 22 min.

Raw Water: Source: Potomac River. Turbidity: 20 ppm. pH: 8.2. Temperature: 74°F.
Treatment: Precoat: 1.0 pound Sorbo-Cel followed by 0.5 pound Sorbo-Cel mixed with 0.25 pound activated carbon (Nuchar F.A.N.). Slurry Feed: 120 ppm (av.)

Procedure and Remarks: The precoat of 1.0 pound of Sorbo-Cel (0.15 lb./ft.^{2}) was applied by recirculating the precoat water to which no cysts had been added. The slurry and cysts were applied through the hypochlorinator. The water used contained very little suspended clay but contained considerable algae and color. Total water filtered: 485 gallons.

Fig. 46

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experiment Number 8-D
Sheet 2 of 2

June 8, 1943

Sample Number	Effl. pH	Effluent Turbidity (ppm) St. Louis At Unit	Tindall At Unit	Tindall After 24 Hrs.	Baylis After 24 Hrs.	Alkalinity MO ppm
Raw	8.2	-	-	-	-	31.0
137	5.2	0+	0.1	0.1	0.0+	9.9
138	6.2	0+	0.05	0.1+	0.1	24.9
139	7.7	0+	0.05-	0.2-	0.0+	25.0
140	7.8	0+	0.05	0.2-	0.2	26.9
141	7.9	0+	0.05	0.2-	0.1	27.0
142	7.9	0+	0.05-	0.2-	0.1	27.3

Remarks: The low alkalinity value for Sample No. 137 and the following rise in both alkalinity and pH can be attributed to the presence of activated carbon in the precoat.

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experiment Number 9-D
Sheet 1 of 2

June 8, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press. psi	Effl. Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-5	15	8	3	-	-	Precoating	Water recirculated
143	0	28	10	4	0/	0	Filtering	pump opened to
144	5	27	10.5	4	0/	0	Filtering	full capacity
145	10	24	13	4	0/	0	Filtering	
146	15	24	13.5	4	0.1	0	Filtering	Engine speed
147	20	24	13.5	4	0.1	0	Filtering	fluctuating
148	25	24	14	4	0.1	0	Filtering	

Raw Water: Source: Potomac River, Turbidity: 20 ppm, pH: 8.2, Temperature: 74°F.
Treatment: Precoat: 1.0 pound Sorbo-Cel (0.15 lb/ft^2), Slurry feed: 120 ppm (av)*

Procedure and Remarks: The precoat was applied by recirculation of precoat water to which no cysts had been added. *The slurry feed was adjusted continuously to maintain rate of pressure rise at a minimum throughout the operation. Cysts were applied continuously through the hypochlorinator. Total water filtered: 648 gallons.

Fig. 48

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experiment Number 9-D
Sheet 2 of 2

June 8, 1943

		Effluent Turbidity (ppm)				
Sample Number	Effl. pH	St. Louis At Unit	Tindall At Unit	Tindall After 24 Hrs.	Baylis After 24 Hrs.	Alkalinity MO ppm
Raw	8.2	-	-	-	-	31.0
143	7.9	0/	.05/	0.3	0.2	27.5
144	7.9	0/	0.1	0.7	0.7	27.5
145	7.9	0/	0.1/	0.6	0.7	27.5
146	7.9	0.1	.2	0.7	0.7	27.5
147	7.9	0.1	.1	0.5	0.5	27.5
148	7.9	0.1	.1	0.5	0.3	27.5

<u>Remarks</u>: Increase in turbidity due in part to color which had coagulated. Turbidity of supernatant of samples after 24 hours was approximately the same as that found at the unit.

Fig. 49

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experimental Number 10-D
Sheet 1 of 4

July 6, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press psi	Effl. Press psi	Effl. Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-10	20	20	2	-	-	Precoating	Chlorine added to
-	0-7	-	-	-	-	-		100 ppm
-	0-2	27.5	22	2	-	-	Filtering	Dechlorinated
149-A	0	-	20	2	0.1-	-	Filtering	Cysts applied
149	1-2	24	20	2	0.1	0	Filtering	
150	2-3	18	22	2	0.1	1	Filtering	
151	3-4	16	22	2	0.1	0	Filtering	
152	4-5	14	24	2	0.2	0	Filtering	

Raw Water: Source: Potomac River. Turbidity: 50 ppm. pH: 7.6. Temperature: 72°F.
Treatment: Precoat: 1.0 pound Sorbo-Cel (0.15 lb/ft^2). Slurry Feed: None.

Procedure and Remarks: The precoat was applied by recirculation of water containing 100 ppm chlorine. The unit was dechlorinated and the cysts applied in a batch. No slurry was used.

Fig. 50

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experiment Number 11-D
Sheet 2 of 4

July 6, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press. psi	Effl. Press. psi	Effl. Turb. ppm	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-12	-	-	-	-	-	Precoating	Chlorine added to 100 ppm
-	0-10	22	24	2	-	-		Dechlorinated
153-A	0	-	-	-	0.1-	-	Filtering	Cysts added
153	1-2	17	22	2	0.1-	0	Filtering	
154	2-3	18	24	2	0.1-	0	Filtering	
155	3-4	13	24	2	0.1-	0	Filtering	
156	4-5	12	25	2	0.1-	0	Filtering	

Raw Water: Source: Potomac River, Turbidity: 50 ppm, pH: 7.6, Temperature: 72°F.
Treatment: Precoat: 1.0 pound Super-Cel (0.15 lb/ft^2); Slurry feed: None.

Procedure and Remarks: The precoat was applied by recirculation of water containing 100 ppm chlorine. The unit was dechlorinated and the cysts applied in a batch. No slurry was used.

Fig. 51

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experiment Number 12-D
Sheet 3 of 4

July 6, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press P.S.I.	Effl. Press P.S.I.	Effl. Turb P.P.M.	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-9	26.5	20	2	1.5+	-	Precoating	Chlorine added
-	0-3	-	-	-	1.5+	-		to 100 p.p.m.
157-A	0	25.0	20	2	1.5+	-	Filtering	Dechlorinated
157	1-2	18.5	22	2	1.5+	0	Filtering	cysts applied
158	2-3	16	22	2	1.5+	1	Filtering	
159	3-4	14	22	2	1.5+	0	Filtering	
160	4-5	13	23	2	1.5+	0	Filtering	

<u>Raw Water</u>: Source: Potomac River, Turbidity: 50 p.p.m. pH: 7.6, Temperature: 72°F.
<u>Treatment</u>: Precoat: 1.0 pound Hyflo Super cel (0.15 lb/ft^2), Slurry Feed: None

<u>Procedure and Remarks</u>: The precoat was applied by recirculation of water containing 100 p.p.m. chlorine. The unit was dechlorinated and the cysts applied in a batch. No slurry was used.

Fig. 52

Diatomaceous Silica Filter, Model SFC-1
Cyst Removal With Converted Portable Sand Filter
The Engineer Board and United States Public Health Service

Experiment Number 13-D
Sheet 4 of 4

July 6, 1943

Sample Number	Elapsed Time Min.	Output G.P.M.	Infl. Press. psi	Effl. Press. psi	Effl. Turb. psi	Cysts Recovered Per Gallon of Effluent	Operation	Remarks
-	0-12	-	-	-	-	-	Precoating	Chlorine added to
-	0-3	32	20	2	1-	-		100 ppm Dechlorinated
161-A	0	29	20	2	-	-	Filtering	cysts applied.
161	1-2	26	22	2	6-10	0		
162	2-3	22	22	2	10+	0		
163	3-4	20	23	2	10+	0		
164	4-5	18	25	2	10+	0		

Raw Water: Source: Potomac River, Turbidity: 50 ppm, pH: 7.6, Temperature: 72°F.
Treatment: Precoat: 1.0 pound JM #545 (0.15 lb/ft^2), Slurry Feed: None

Procedure and Remarks: The precoat was applied by recirculation of water containing 100 ppm chlorine. The unit was chlorinated and the cysts applied in a batch. No slurry was used. Note absence of cysts in presence of 10-15 ppm turbidity in effluent.

Fig. 53

Diatomaceous Silica Filter, Model SFC-1
Summary Bacterial Removal With Several Grades of Filteraid
The Engineer Board and United States Public Health Service

Experiment Nos. 10-D & 13-D
Sheet 1 of 1

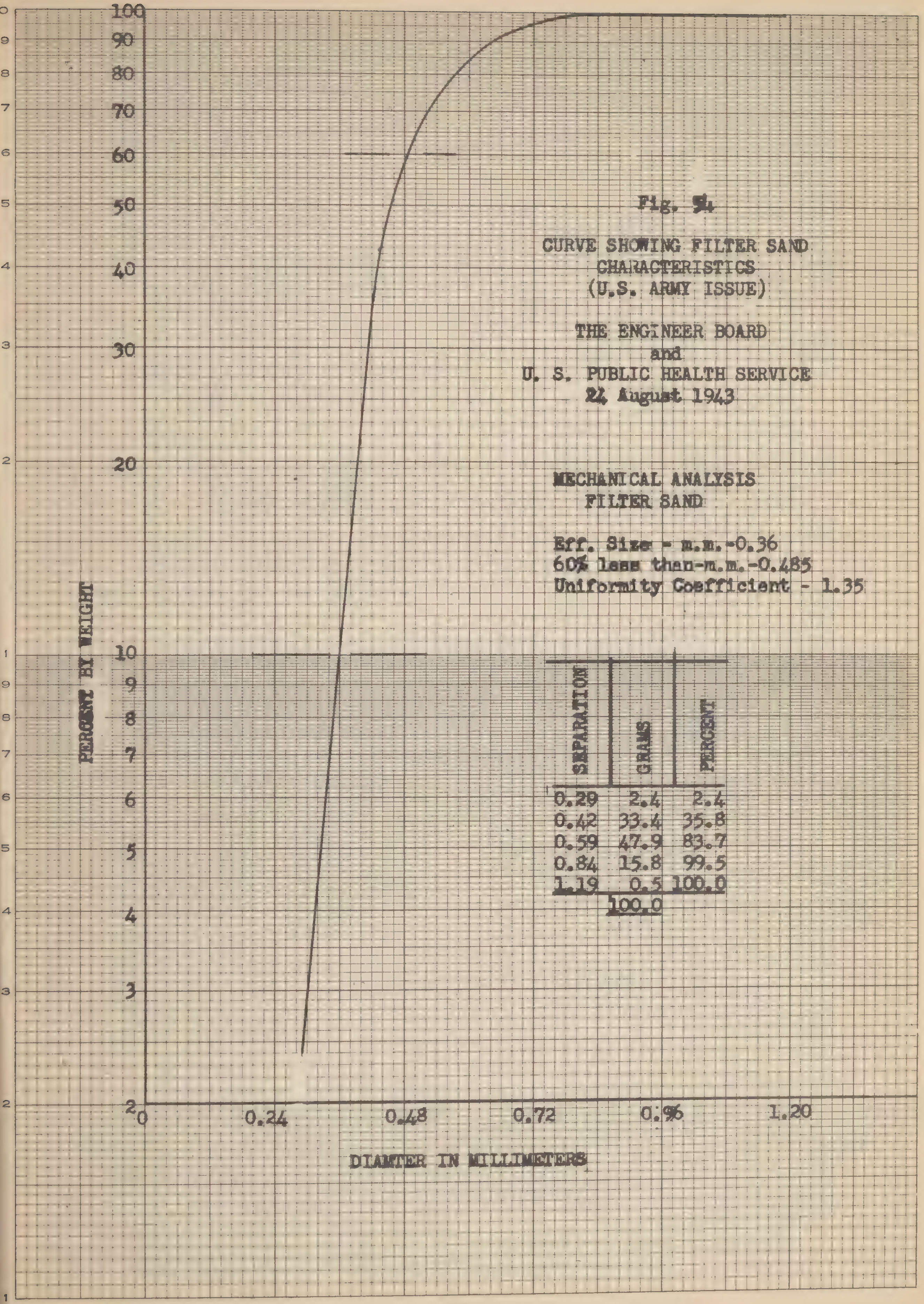
July 6, 1943

Test No.	Filteraid Used	Sample Number	Bacterial Count Per c. c. 37°C	Smallest Quantity Positive For B. Coli
		Raw*	445	0.1 c.c.
10-D	Sorbo-Cel	149-A	Bact. absent in 0.1 c.c.	1.0 c.c.
		152	40	10 c.c.
11-D	Super-Cel	153-A	40	(absent)10 c.c.
		156	20	(absent)10 c.c.
12-D	Hyflo	157-A	30	1.0 c.c.
		160	120	1.0 c.c.
13-D	$545	161	340	.01 c.c.
		164	120	1.0 c.c.

Remarks: *Average of 4 samples.

APPENDIX C

SAND ANALYSIS



SEPARATION	GRAMS	PERCENT
0.29	2.4	2.4
0.42	33.4	35.8
0.59	47.9	83.7
0.84	15.8	99.5
1.19	0.5	100.0
	100.0	

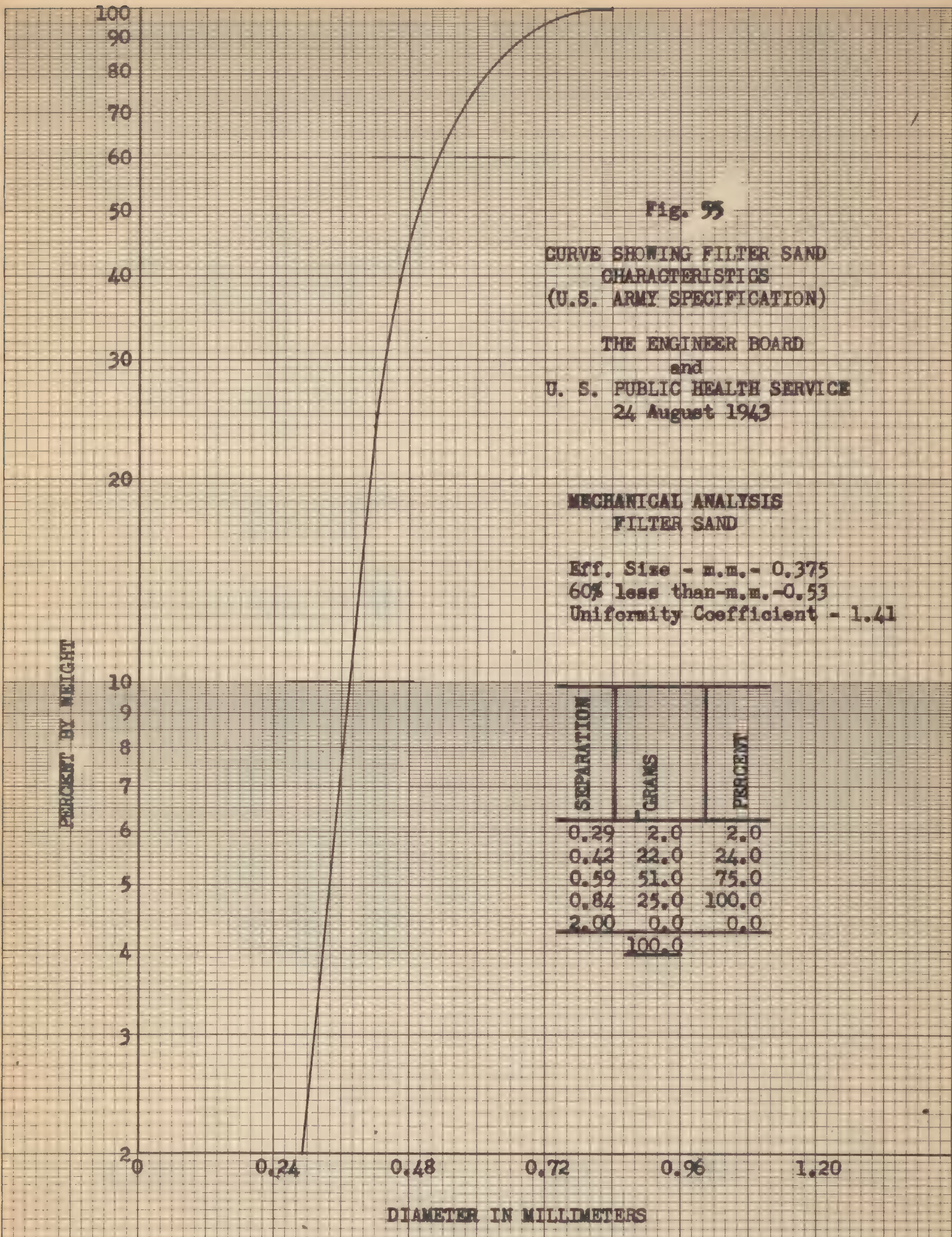


Fig. 95

CURVE SHOWING FILTER SAND
CHARACTERISTICS
(U.S. ARMY SPECIFICATION)

THE ENGINEER BOARD
and
U. S. PUBLIC HEALTH SERVICE
24 August 1943

MECHANICAL ANALYSIS
FILTER SAND

Eff. Size - m.m.- 0.375
60% less than-m.m.-0.53
Uniformity Coefficient - 1.41

SEPARATION	GRAMS	PERCENT
0.29	2.0	2.0
0.42	22.0	24.0
0.59	51.0	75.0
0.84	25.0	100.0
2.00	0.0	0.0
	100.0	